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EVALUATION OF METAL LANDING GEAR DOOR ASSEMBLY SELECTIVELY REINFORCED WITH FILAMENTARY COMPOSITE FOR SPACE SHUTTLE APPLICATION

FINAL REPORT

by

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FOREWORD

This report was prepared by the McDonnell Douglas Astronautics Company (MDAC), Advance System and Technology Division, Huntington Beach, California, under the terms of Contract NAS1-10785. It is the final report on this program and covers all three phases of the work that was completed between May 1971 and June 1972. The program was sponsored by the National Astronautics and Space Administration's Langley Research Center, Hampton, Virginia. Mr. John Davis, Jr. was the Contracting Officer's Representative.

The following McDonnell Douglas Corporation personnel were the principal contributors to the program Dr. H. C. Schjelderup of Douglas Aircraft Company, program manager; C. Y. Kam, MDAC, deputy program manager; S. J. Kong, MDAC, principal investigator; G. H. Fisher, MDAC, design; V. L. Freeman, MDAC, materials and processes; and H. Sirotnik, MDAC, structural testing.

All numerical values used in measurements and calculations in this report are expressed in the International (SI) System of Units. Equivalent U. S. Customary Units are given in parentheses following the SI values.

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CONTENTS

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FIGURES

Page

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TABLES

EVALUATION OF METAL LANDING GEAR DOOR ASSEMBLY SELECTIVELY REINFORCED WITH FILAMENTARY COMPOSITE FOR SPACE SHUTTLE APPLICATION

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SUMMARY

This is the final report on the effort performed for the NASA Langley Research Center by McDonnell Douglas Astronautics Company (MDAC) under Contract NAS1-10785. It summarizes the development work accomplished and the results obtained in a program to evaluate a main landing gear door utilizing advanced composites for Space Shuttle application.

Initial efforts were directed mainly to the design and development of a hybrid structure for the door, which featured a rib-stiffened titanium panel selectively reinforced with boron/epoxy composite. A weight comparison between the hybrid design and the all-titanium baseline design indicated a weight saving of slightly less than the 15-percent goal. Subsequently, four alternate concepts were investigated. A full-depth honeycomb concept was selected because of its acceptable weight saving and its ease of fabrication.

Design drawings for both a full-size door, 4.5 by 1.4 m (177 by 55 in.), and a door sector, 0.84 by 1.4 m (33 by 55 in.) were generated. Weight estimates for the full-size door design were made for comparison with other door design concepts. The door sector, which featured all the structural components in the full-size door, was fabricated and evaluated in a structural testing program.

In the interest of minimum weight, a six-ply pattern of $[0/(45)^{Q}/90]_s$ was used for Narmco 5206-Type II graphite/epoxy facing rather than adding two extra plies to achieve perfect balance. This pattern produced a slight warpage in the facing. However, with the $\pm45^\circ$ crossplies properly oriented in each skin, the door panel became a balanced sandwich structure after the two skins were bonded to the core.

The honeycomb core was of 0.477-cm (3/16-in.) cells 0.0025 cm (0.001 in.) thick. The core material was 5052 aluminum of 49.7 kg/m^3 (3.1 lb/ft^3) density. Specially designed metallic core inserts were bonded with FM40 foaming adhesive to the honeycomb core to diffuse the localized loads acting on the column fitting, latches, and hinges. The insert design was basically an I-section. Its web was undercut, and the flanges were tapered to reduce

mismatch of stiffness between the honeycomb core and the insert, and to minimize the tendency toward skin-piercing by the local insert.

The skins with the integral couplers were hand-laid and cured individually. The integral-doubler fabrication approach saved the time and expense involved in individual curing and postbonding of doublers. The skins were bonded to the core-insert subassembly with Metlbond 329 film adhesive in an autoclave.

Other structural components fabricated included a titanium pivot beam and a titanium column selectively reinforced with unidirectional boron/epoxy.

The graphite/epoxy door was instrumented with 13 strain gages, 9 thermocouples, and 2 deflection potentiometers. The door sector assembly was subjected to three structural tests. The first test was conducted on the door to the condition A loading of a uniform pressure of 59.3 kN/m^2 (8.6 psi) ultimate. In this test, the door was simply supported at the short 0.84-m (33-in.) edges. In the second test, the door was installed in a test rig corresponding to the opened position with the column and the pivot beam mounted in place. A pressure cycle of 0 to 2.0 kN/m^2 (0 to 0.29 psi) limit was applied to the assembly 400 times as specified in condition D.

The second test was concluded with the application of a uniform static pressure of 2.76 kN/m^2 (0.40 psi) ultimate. The third and last test was conducted on the door at 394°K (250°F) to the condition B loading. The door was supported at the hinges and the latches, and was loaded with a concentrated force at the column fitting. The door was first tested to the limit load of 25,000 N (5,630 lb), then to the ultimate load of 35,100 N (7,880 lb), and finally to failure at 230 percent of limit load, or 57,500 N (12,950 lb). Based on the minimum margin of safety of +0.73, the predicted failure load was 60,500 N (13,600 lb).

A final weight saving of 27.3 percent was achieved for the full-size graphite/epoxy door over a comparable all-aluminum door.

INTRODUCTION

The high dollar value of weight saved in reusable space systems such as the Space Shuttle has made attractive (from the standpoint of cost effectiveness based on total program costs) the structural application of advanced composites to some selected areas. The main landing gear door assembly (MLGDA) of the Space Shuttle was selected for this development program because it had significant weight saving potential, encompassed a wide variety of assembled structural elements, was applicable to all shuttle vehicles and other spacecraft, and represented well-established design and fabrication experience. The geometric configuration of the MLGDA selected for evaluation in this program was made to conform with the conceptual design of the high-cross-range (HCR) orbiter of the phase B Space Shuttle.

The development program was divided into three phases of investigation. Phase I dealt with the design and analysis of the door assembly, and the testing of coupons and subscale structural components. Detailed documentation of phase I work is contained in reference 1. Phase II was concerned primarily with the fabrication of the test door sector assembly and test fixture. A detailed description of the step-by-step fabrication procedures can be found in reference 2. Phase III dealt with the structural testing of the door sector assembly. The test activities in this phase were reported in reference 3. The period of performance for the three phases was from April 1971 to July 1972.

The assistance of the following personnel during the various phases of the program is hereby acknowledged:

- Dr. John Hart-Smith of Douglas Aircraft Company, Long Beach, California, who performed the stress analysis of the door panel and was consulted during various stages of the design activity.

- The personnel of the Composite Laboratory of Douglas Aircraft Company, under the direction of Mr. R. J. Palmer, for their contributions to investigations of materials and processes, preparation of test specimens, and fabrication of the hybrid column and the graphite/epoxy test door sector.

- The personnel of the Engineering Laboratories at MDAC, Huntington Beach, California, for conducting the structural tests and performing associated tasks.

DESIGN CRITERIA, DESIGN CONDITIONS, AND LOAD ANALYSIS

Design Criteria

This section outlines the structural design criteria required for the design, analysis, fabrication, and test of the middle sector of the MLGDA. References 4 through 9 were used as the basis for establishing material allowables and design requirements.

Design yield load.— At design yield load, there shall be no yielding of the structure that may result in impairment of the functional requirements of the MLGDA.

Design ultimate load.—At design ultimate load, there shall be no failure of the door structural assembly. Buckling is considered to be an ultimate failure.

Factors of safety. — The following factors of safety will be used in the design and analysis of the MLGDA:

1. Factor of safety = 1.4.

2. Dynamic magnification factor

$$\text{Ascent} = 1.3 + 0.1 \left(\frac{q}{q_{max}}\right)$$

$$\text{Descent} = 1.2$$

Temperatures.—The wheel wells are assumed to be thermally regulated by the environmental control subsystem as well as a thermal protection system (TPS) on the door. With these thermal systems and seals on the edges of the door, the operating temperatures of the MLGDA range between 219°K (-65°F) and 394°K (250°F). Landing gear tires and hydraulic fluid in the actuators are protected under this temperature condition.

Load factors.—Load factors are as follows:

1. Ascent = 3.0 longitudinal.

2. Airplane = +2.5, -1.0 normal.

Strength requirements.—The MLGDA will be designed to have sufficient strength to withstand simultaneously the design yield loads and other accompanying environmental phenomena for each design condition without experiencing detrimental yielding.

The structure will be designed to withstand simultaneously the design ultimate loads and other accompanying environmental phenomena without failure.

Stiffness. Under limit loads, the MLGDA is required not to experience deformations that would impair functional performance.

Cyclic loads: The effects of repeated loading will be considered in the design. The number of cycles has been established as 400.

Design Conditions

The structural requirements for the MLGDA were established. The requirements consisted of definition of the landing and inflight loads and the temperature histories expected. Four critical design conditions emerged:

1. Design condition A–An ultimate uniform pressure, p_A, of 59,200 N/m^2 (8.6 psi) acting on the door in closed position at room temperature. This is the ultimate interference pressure on the MLGDA during Shuttle ascent.

2. Design condition B–An ultimate actuator load of 177,920 N (40,000 lb) acting on the door assembly with door closed at 394°K (250°F). This opening load from the hydraulic cylinder actuator rod occurs in the event that the door latches jam just prior to opening.

3. Design condition C—An ultimate pressure, p_C, of 4,690 N/m^2 (0.68 psi) acting on the down-position opened door at 394°K (250°F). This aerodynamic load can occur in a hard yaw approach to the landing area.

4. Design condition D—An ultimate pressure of 2,760 N/m^2 (0.4 psi) applied 400 times on the down-position opened door at room temperature. This cyclic loading results from ground-effect aerodynamic loads on doors at touchdown.

It is noted that for design conditions A, B, and D, in which pressure loadings are acting, a dynamic magnification factor of 1.40 was used in analyzing the door assembly.

Load Analysis

Based on the four design conditions listed above, a load analysis was conducted for the door assembly, which included the door panel, the column, the beam, and the actuator (fig. 1). These components form a linkage system for the operation of the door. The closed position is assumed by the door during operation of design conditions A and B. In design condition A, the door, under uniform pressure, rests on the seal around its periphery. It was assumed that under this loading, the door was sufficiently rigid that the forces in the linkage system were equal to zero. The opened position is assumed by the door during operation of design conditions C and D. Pressure loads are transmitted through the linkage system to the airframe.

Free-body diagrams for the aforementioned door positions are shown in figures 2 and 3. In the computations of reactions at the hinges, latches, and center column fitting of the door for design condition C, the pressure distribution was assumed to be semielliptical spanwise and bitriangular chordwise. The total pressure force, p x A, of this distribution was made equal to the total pressure force of the uniform pressure of 4,690 N/m^2 (0.68 psi). The results of the load analysis are shown in table 1.

DESIGN AND DEVELOPMENT TEST

Preliminary Tradeoff Studies and Material Selection

The design effort was originally directed toward a metal structure selectively reinforced with composites for the main landing gear door components. For evaluation of the selectively reinforced structural concept, an all-titanium door panel was first designed. This preliminary design featured a rib-stiffened panel. The shear loads were transmitted by the ribs and intercostals. The bending moment was reacted by tension and compression in the panel skins. The panel was sized based on the four design conditions. Buckling of the panel skin was found to be critical. The all-titanium design was then modified into a hybrid concept by reinforcing the titanium sheets

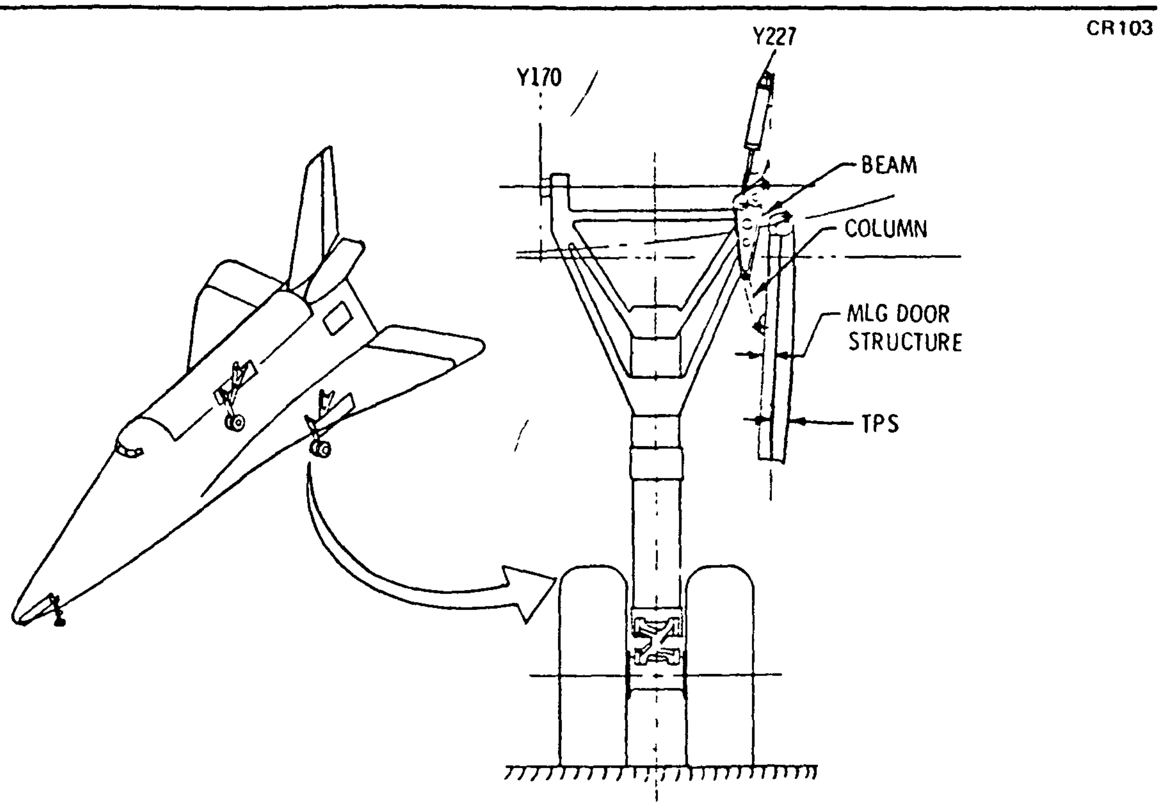

Figure 1 Main landing gear door assembly

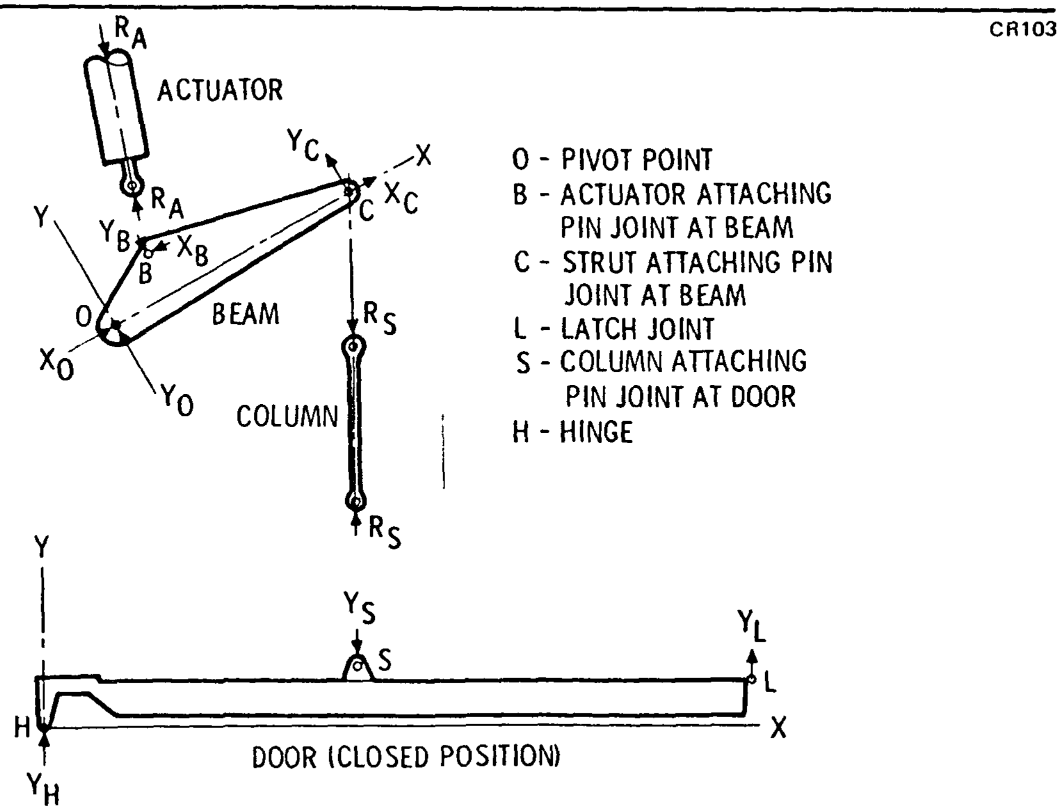

Figure 2 Free-body diagrams of door linkage assembly – design condition B

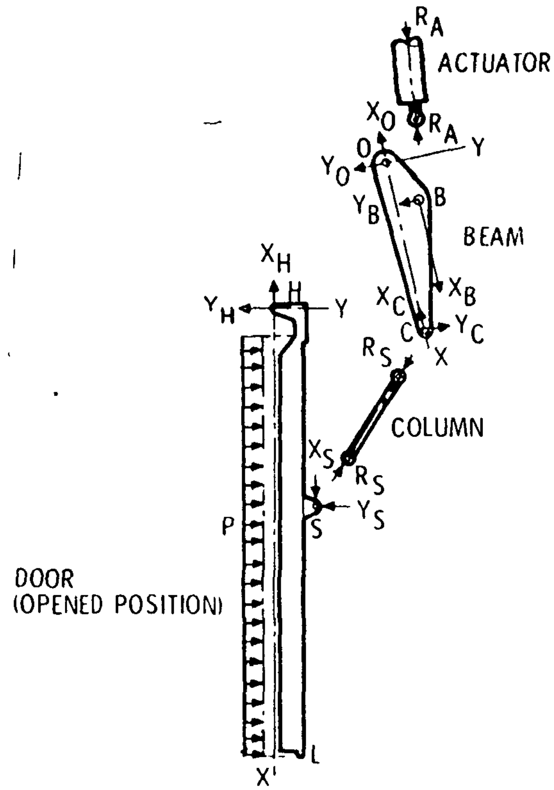

Figure 3 Free-body diagrams of door linkage assembly – design conditions C and D

selectively with boron/epoxy (B/Ep) composite. The hybrid panel was also sized for the same design conditions as the all-metal panel.

A weight comparison made between the two designs indicated that the weight saving of the hybrid design over the all-metal design was less than 15 percent. One important factor that accounted for the strong showing of the all-titanium design was the use of thinner-gage titanium skins made possible by the effective-width analytical approach. With this approach, a portion of the panel skin, defined as the effective width, acts together with the stiffening rib as a column to resist the compressive load. The remaining portion of the skin between the rib stiffeners is allowed to buckle.

For the hybrid design, postbuckling capacity of the boron/epoxy-reinforced titanium sheet has not been established. With the strain mismatches existing in a composite of titanium sheet, film, adhesive, and boron/epoxy laminates, the ability to function in a postbuckled state is somewhat questionable. Thus, the hybrid panel was designed so that it would not buckle.

These two different design approaches significantly influenced the outcome of the weight comparison. Design efforts were then directed to the study of other concepts that would produce higher weight savings. Preliminary conceptual designs of the door were made utilizing filamentary composites. These designs, all based on the same design conditions used previously, are discussed in the sections that follow.

Full-depth honeycomb panel—design I. —This concept (fig. 4) utilizes a lightweight plastic honeycomb core as shear load carrier and graphite/

TABLE 1

SUMMARY OF MLGDA DOOR LINKAGE FORCES

Component	Symbol of force or reaction	Ultimate force on reaction for design condition										
		A	B		C				D			
					Forward actuator		Aft actuator		Forward actuator		Aft actuator	
		See notes	kN	(lbf)	kN	(lbf)	kN	(lbf)	kN	(lbf)	kN	(lbf)
Actuator	R_A		178 0	40,000	117 3	26,390	70 4	15,835	69 0	15,520	41 4	9,310
Beam	X_O		38 2	8,575	94 0	21,085	56 3	12,650	55 2	12,400	33 1	7,440
	Y_O		139 0	31,230	7 4	1,675	4 5	1,005	4 4	990	2 6	590
	X_B		55 0	12,350	116 0	26,110	69 7	15,665	68 3	15,360	41 0	9,210
	Y_B		169 2	38,050	17 0	3,810	10 2	2,285	10 0	2,240	6 0	1,340
	X_C		16 8	3,775	22 4	5,025	13 4	3,015	13 2	2,960	7 9	1,770
	Y_C		30 3	6,820	24 4	5,485	14 6	3,290	14 4	3,230	8 6	1,940
Column	R_S		35 1	7,880	33 1	7,440	19 9	4,465	19 5	4,380	11 7	2,630
Door	p, kN/m^2 (psi)	59 3 (8 6)	0	0	4 69 (0 68)				2 76 (0 40)			
	X_H		0	0	27 4	6,170	16 5	3,700	16 1	3,630	9 7	2,180
	Y_H		19 5	4,370	0	0	0	0	0	0	0	0
	X_S		0	0	27 4	6,170	16 5	3,700	16 1	3,630	9 7	2,180
	Y_S		35 1	7,880	18 5	4,160	11 1	2,495	10 9	2,450	6 5	1,470
	Y_L		15 6	3,510	0	0	0	0	0	0	0	0

Notes

1 Door is assumed to be rigid under pressure loading of condition A Linkage forces are equal to zero in this condition

2 Positive directions of forces are as shown in Figures 2 and 3

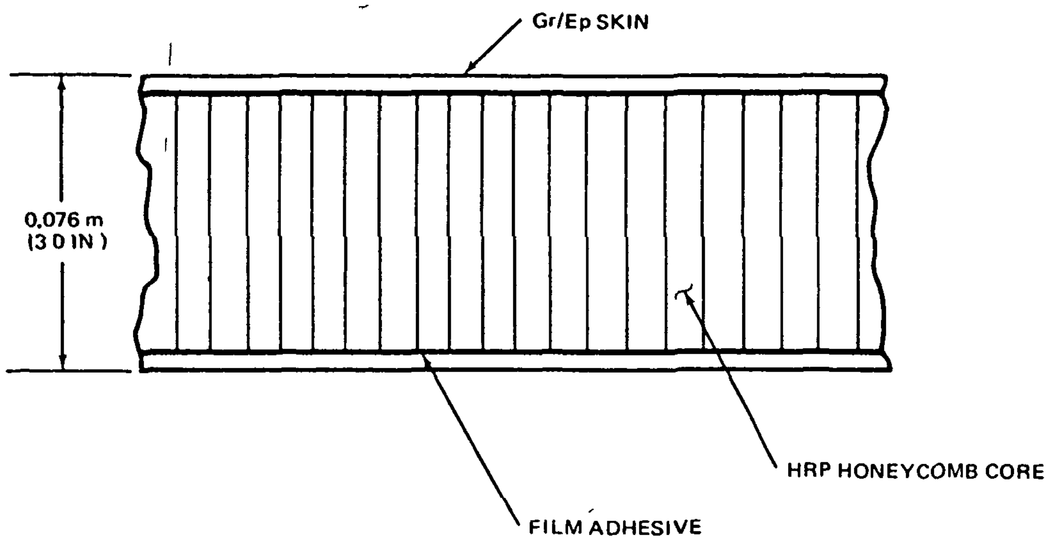

Figure 4 Full-depth honeycomb design

epoxy (Gr/Ep) facings for transmitting tensile and compressive loads caused by bending moments. The advantage of this design is that the skins are stabilized by the core and will not be buckling-critical.

Based on this preliminary design, the weight was estimated to be 96.6 kg (212.8 lb). This estimated weight gives a 38.1-percent weight saving over the 156.0 kg (343.9 lb) estimated for the all-titanium, rib-stiffened panel.

Rib-stiffened panel with honeycomb skin—design II. —This preliminary design (fig. 5) represents a door concept that utilizes advanced composite for the major structural components. The panel is rib-stiffened. The ribs and intercostals are made of graphite/epoxy. They are joined by graphite/epoxy clips that are mechanically fastened to the webs of the stiffeners. The rib stiffeners are spaced 0.127 m (5.0 in.) apart as in the baseline titanium design.

The weight estimate of this design was found to be 97.4 kg (214.8 lb). The weight saving over the all-titanium baseline was 37.7 percent.

All-composite rib-stiffened panel—design III. —This design concept (fig. 6) is similar to the design described in the preceding subsection, with the following exceptions:

1. The graphite/epoxy skins of eight-ply balanced laminate of $[0/\pm45/90]_s$ are allowed to buckle. In other words, this design

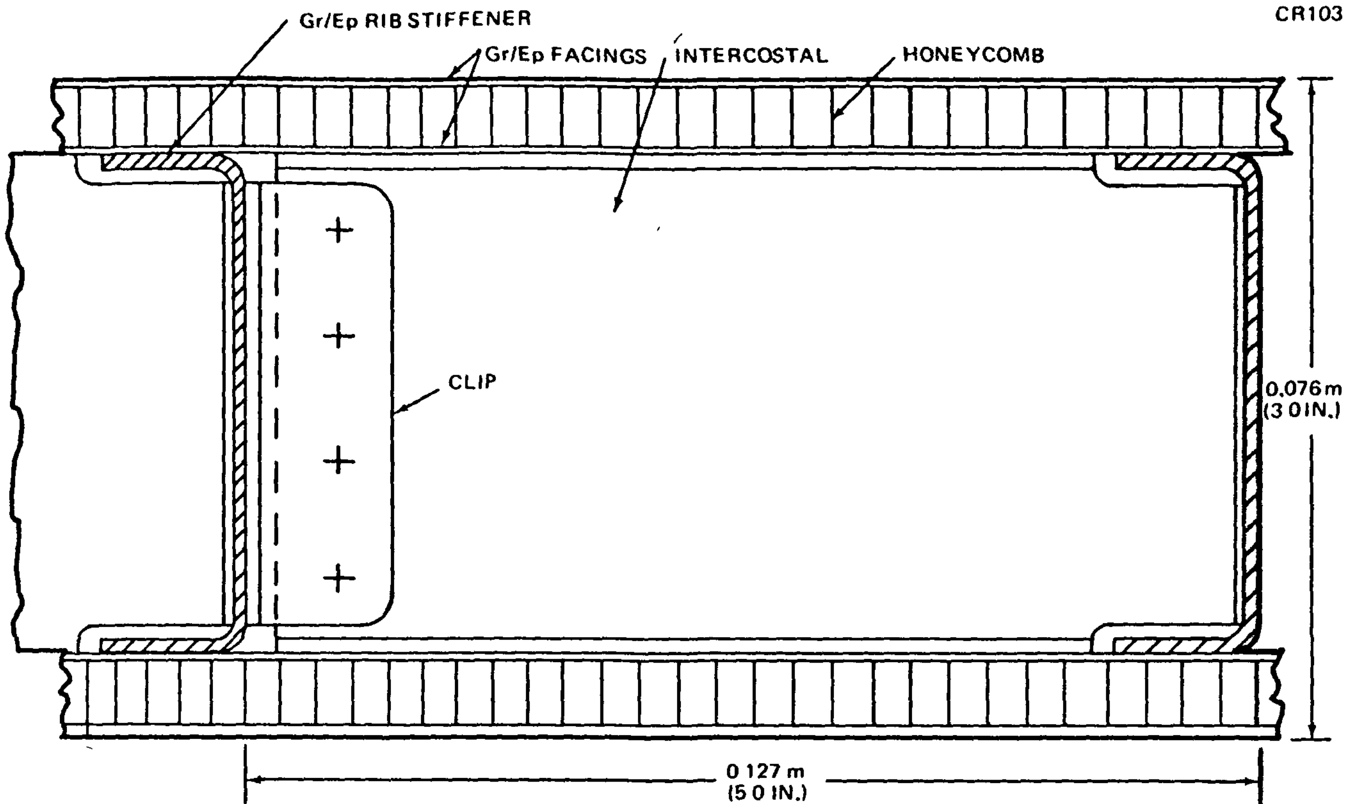

Figure 5 Rib-stiffened door panels with honeycomb skins

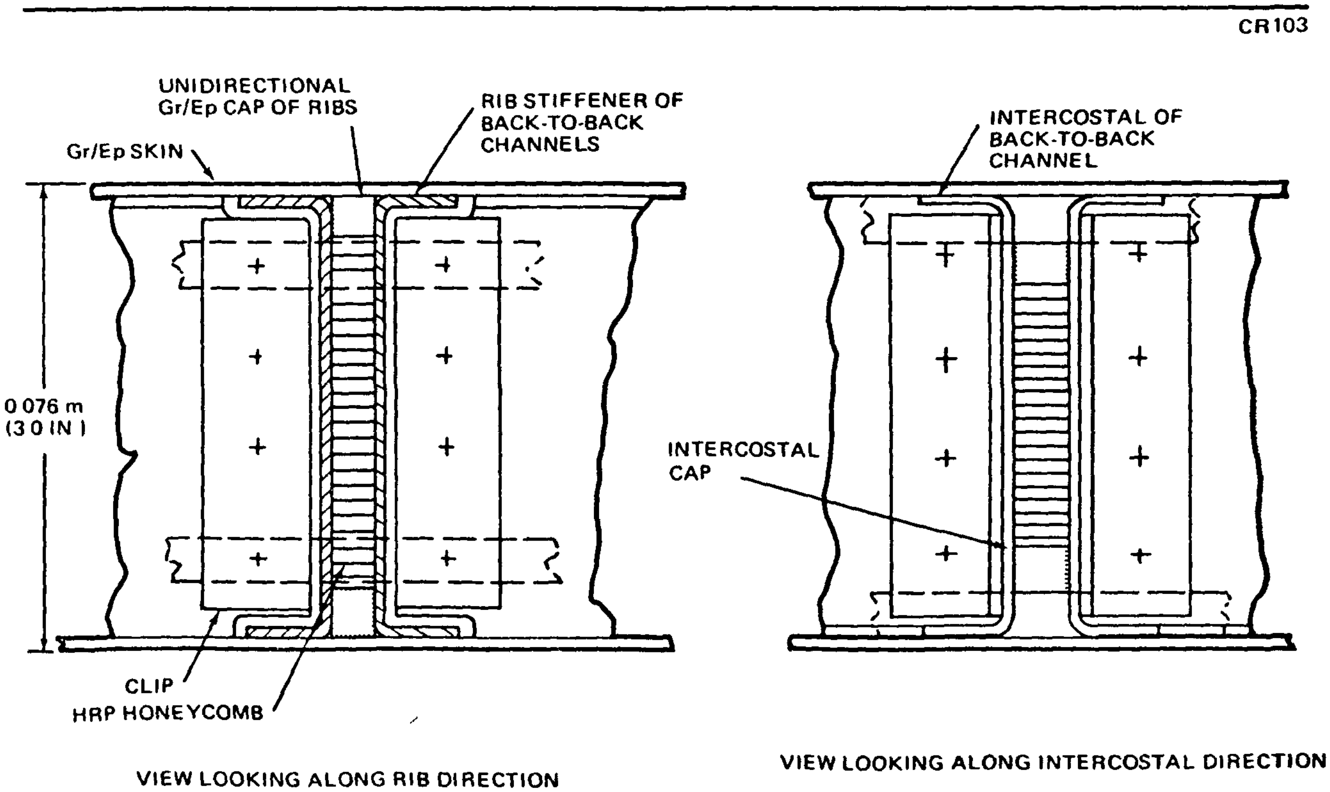

Figure 6 All-composite, rib-stiffened design

assumes that the Gr/Ep laminates are capable of functioning in a postbuckled state.

2. The ribs and intercostals are made of back-to-back graphite/epoxy channel sections bonded to a honeycomb core at the webs. In an area at the top and bottom of the ribs bounded by the webs and the skin, a unidirectional graphite/epoxy cap of square cross section is located. The cap is the main structural member to transmit the bending compressive load while the skin is in the buckled state.

This design was estimated to weigh 93.3 kg (205.3 lb). A weight comparison made between this all-composite design and the baseline design indicates a weight saving of 40 percent for this graphite/epoxy door.

Boron/epoxy-reinforced titanium panel—design IV. —This design concept (fig. 7) retains the original approach of metal structure selectively reinforced with filamentary composite. The basic design philosophy is the same as for the all-composite rib-stiffened panel in that the panel skins are allowed to buckle and the bending compressive loads are transmitted by the unidirectional cap members. In this instance, the cap members are made of boron/epoxy, and the remaining structures of the door are made of titanium.

The unidirectional boron/epoxy caps are of triangular cross section. This shape facilitates the containment of the cap in the formed sheet metal parts.

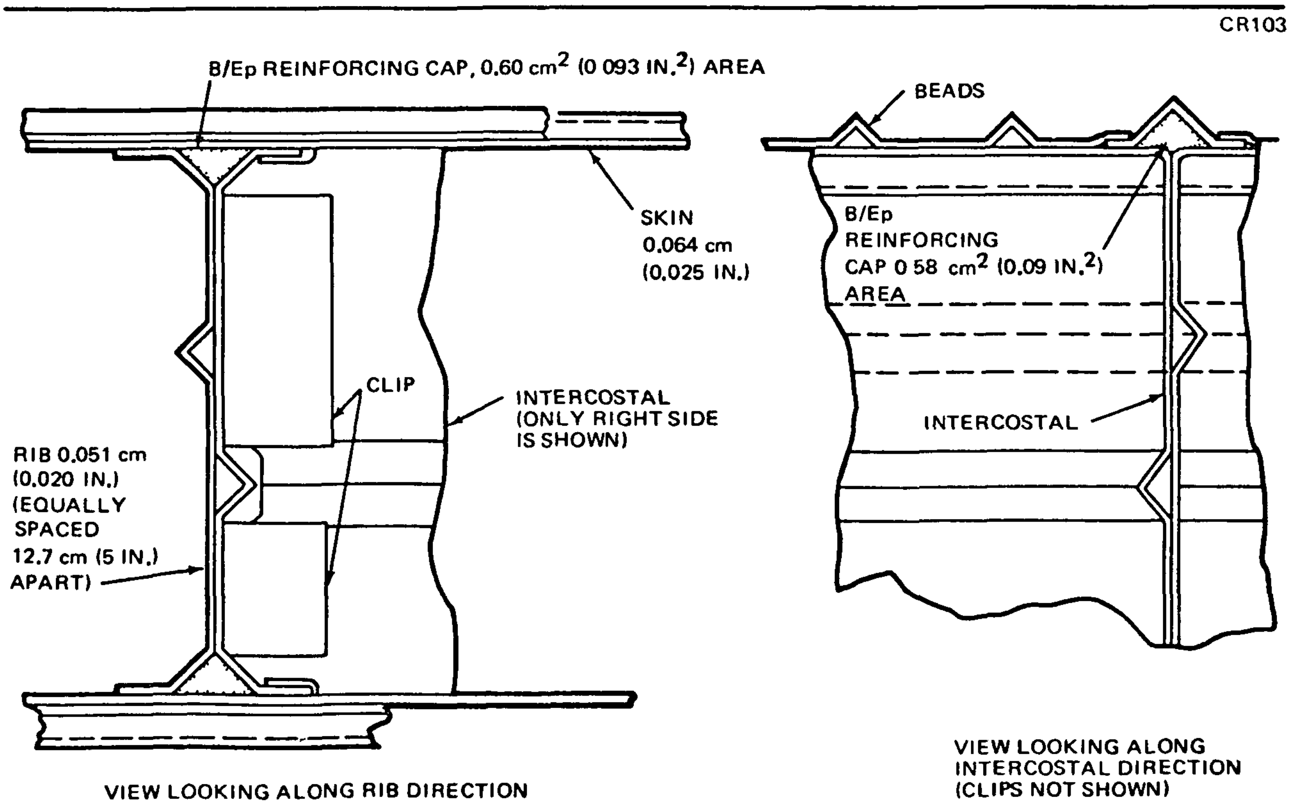

Figure 7 Boron/epoxy-reinforced titanium door panel

The weight estimate of 121.5 kg (267.4 lb) for this door design shows a weight saving of 22 percent over the baseline all-titanium design

Concept selection. Based on the results of the preliminary design tradeoff studies discussed above, designs I, II, and III have approximately the same weight, while design IV is significantly heavier. Therefore, from the weight standpoint, design IV is less desirable.

Design III has the highest weight saving. The concept presents a challenge for the research and development of the advanced composite material, in that the realization of weight savings hinges on how much postbuckling strength the material will possess. From the fabrication standpoint, this concept appears to be most complex.

Designs I and II utilize honeycomb to stabilize the skin. Their weights are practically the same. However, design II presents a more serious fabrication problem than design I. Hence, based on the consideration of weight savings, fabrication complexity, and risks involved, the alternate design of full-depth honeycomb was selected for further evaluation as the structural concept for the Shuttle orbiter main landing gear door.

After the concept selection was made, the preliminary design of the Gr/Ep sandwich panel was revised to reflect the use of a lighter 5052 aluminum core instead of the heat-resistant phenolic (HRP) core. The core height was reduced from 0.076 m (3.0 in.) to 0.058 m (2.27 in.) so that the six-ply, 0.00091-m (0.036-in.) thick graphite/epoxy skins could be stressed to a predicted allowable strength of 455 MN/m^2 (66,000 psi). This door concept was estimated to weigh 74.8 kg (164.8 lb), as compared with the estimated weight of 89.4 kg (196.8 lb) for an all-aluminum sandwich panel, resulting in a weight saving of 16 percent. Compared to the original concept of rib-stiffened titanium selectively reinforced with boron/epoxy composite, the Gr/Ep sandwich panel offers a weight saving of 81.2 kg (179.1 lb).

Material Selection and Design Allowable

In the interest of conserving the time available for the remainder of phase I, proven materials were used for the full-depth honeycomb door instead of conducting material evaluation tests on several candidates. Thus, for the graphite/epoxy skins, Narmco 5206-type II prepreg was selected because it is being used in the A-4 horizontal stabilizer program at Douglas Aircraft Company. Other proven materials included Metlbond 329 as the skin-to-core adhesive and FM40 as the foaming adhesive for insert-to-core application and core splicing.

Coupon tests of graphite/epoxy were conducted for tensile and compressive strengths at room temperature and at 394° K (250° F). The results of these tests are shown in figures 8, 9, and 10. It appears that the minimum design allowable could be either a tensile strength of 0.383 GN/m^2 (55,500 psi) at room temperature or a compressive strength of 0.355 GN/m^2 (51,500 psi) at 394°K (250°F).

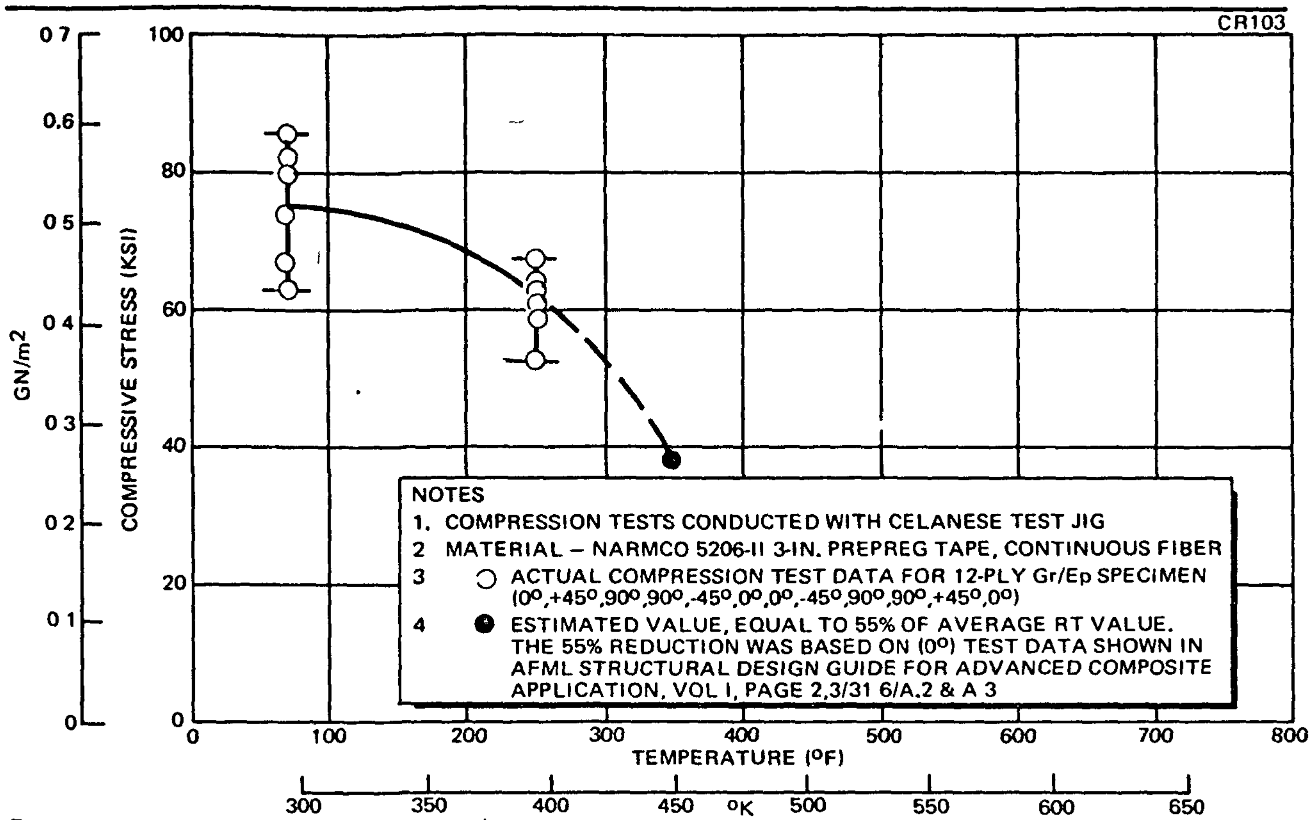

Figure 8 Compressive strength of graphite/epoxy vs temperature

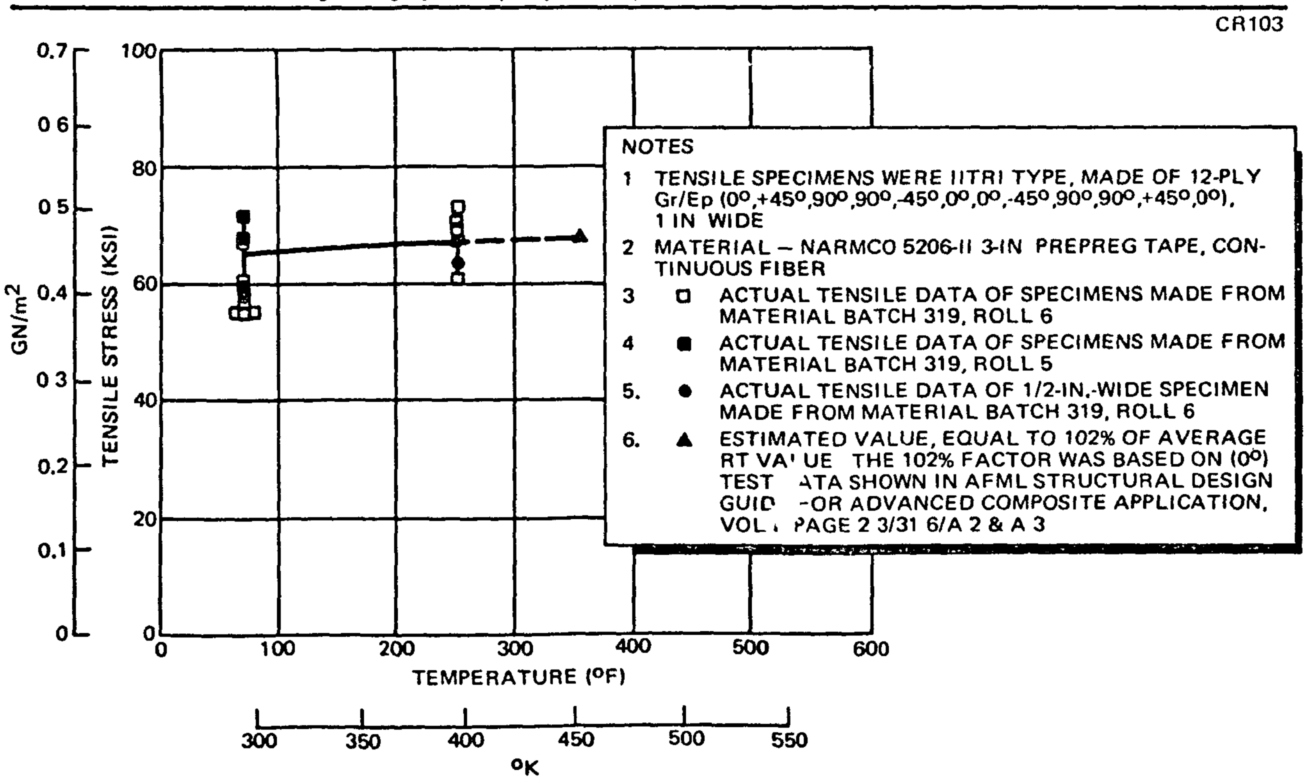

Figure 9. Tensile strength of graphite/epoxy vs temperature

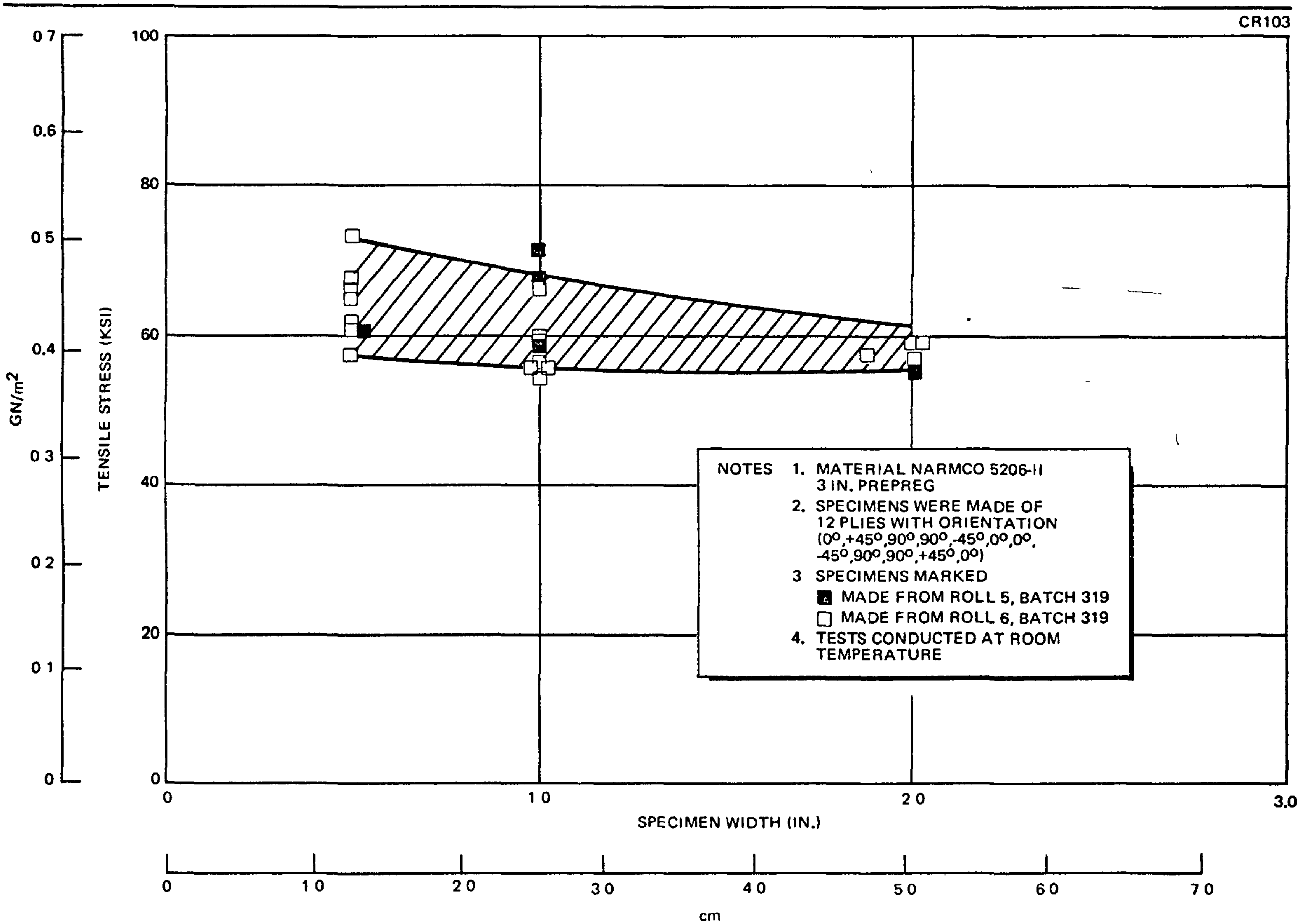

Figure 10 Tensile strength of graphite/epoxy as a function of specimen width

Coupon test results at this juncture of phase I indicated that the allowable strengths appeared to be lower than those theoretically predicted. Due to the schedule commitments of the program, it was necessary that all long-lead items such as metal details and honeycomb core be designed and released for fabrication by this time. These designs were dependent on the core height, which in turn was a function of the facing allowable strengths. It was decided to use the above allowables for design (0.383 GN/m^2 tensile, 0.355 GN/m^2 compressive) to maintain the schedule of the program.

The reasons for the low allowable strengths found in the testing were believed to be (1) the poor and variable prepreg available at the time the testing was performed and (2) the greater scatter and lower mean tensile values obtained with the IITRI* specimens in comparison with the sandwich beam used later. The sandwich beam test data, shown in table 2, indicate a minimum tensile allowable of 0.464 GN/m^2 (67,230 psi) and a minimum compressive allowable of 0.666 GN/m^2 (88,040 psi).

Design and Analysis of MLGDA Components

This section describes the design of the full-size graphite/epoxy door, the test door sector, the connecting column, and the pivot beam. Results of the stress analyses of these components are presented in a table of margins of safety. The full-size graphite/epoxy door was designed only as a model to provide a weight comparison between the composite version and a comparable all-aluminum design.

The baseline for this door design was the phase B Shuttle orbiter main landing gear door design (ref 10). To reduce manufacturing costs, the door was designed as flat honeycomb structure without the inboard and outboard contours shown on phase B preliminary drawings. The design, however, satisfies all the requirements for evaluating advanced composite designs for potential weight savings on the Shuttle orbiter.

Full-size door design. —The overall dimensions of the door are 7.62 cm (3.00 in.) thick, 140.03 cm (55.13 in.) wide, and 450.85 cm (177.50 in.) long (fig. 11). The skin is a quasi-symmetric $[0/(45)^{\Omega}/90]_s$ laminate of Narmco 5202-Type II graphite/epoxy. The opposed face sheets together make a symmetrically balanced cross section. The skin is bonded to the core and fitting flanges with Metlbond 329. The door periphery is closed with an outboard-facing channel section. The channel flange is a 10-ply symmetrical laminate $[0, \pm 45/0/90]_s$ with a six-ply symmetrical laminate web $[\pm 45/90]_s$. The channels, bonded to the honeycomb with foaming adhesive, are clipped together with 10-ply symmetrical laminate $[0/\pm 45/0/90]_s$ clips at the corners and at each latch and hinge fitting.

The core is 5052 aluminum with 0.477- by 0.0025-cm (0.188- by 0.001-in.) cells. The seven titanium hinge fittings (fig. 12) were designed to meet Shuttle orbiter geometric restraints, which provide for clearance of the outboard TPS structure and also sustain the shear and bending loads introduced at the hinge pivot point.

*Illinois Institute of Technology and Research Institute.

TABLE 2

SANDWICH BEAM TEST RESULTS

Speci-men no.	Graphite/epoxy				Beam depth		Ultimate load		Ultimate tensile strength, graphite/epoxy		Ultimate compressive strength, graphite/epoxy	
	Thickness		Width									
	mm	(in.)	cm	(in.)	cm	(in.)	N	(lb)	GN/m^2	(psi)	GN/m^2	(psi)
1	0.865	(0 034)	2.54	(1)	4 02	(1.58)	4,780	(1,075)	0.553	(80,200)	–	–
2	865	(034)	2.54	(1)	4.02	(1.58)	4,370	(983)	.505	(73,300)	–	–
3	865	(.034)	2.54	(1)	4.02	(1.58)	5,160	(1,160)	.595	(86,400)	–	–
4*	.900	(035)	2 54	(1)	4.02	(1.58)	4,210	(947)	.464	(67,230)	–	–
5*	930	(.037)	2.54	(1)	4.02	(1.58)	5,160	(1,160)	.550	(80,490)	–	–
6*	.896	(.035)	2.54	(1)	4.02	(1 58)	6,020	(1,353)	–	–	0 666	(96,900)
7*	.890	(.035)	2.54	(1)	4.02	(1.58)	5,430	(1,220)	–	–	666	(88,040)

*In-process quality control specimens cut from door sector skins as described under "In-process quality control testing."

Figure 11. Aluminum honeycomb door assembly, MLGDA graphite/epoxy (IT 42086)

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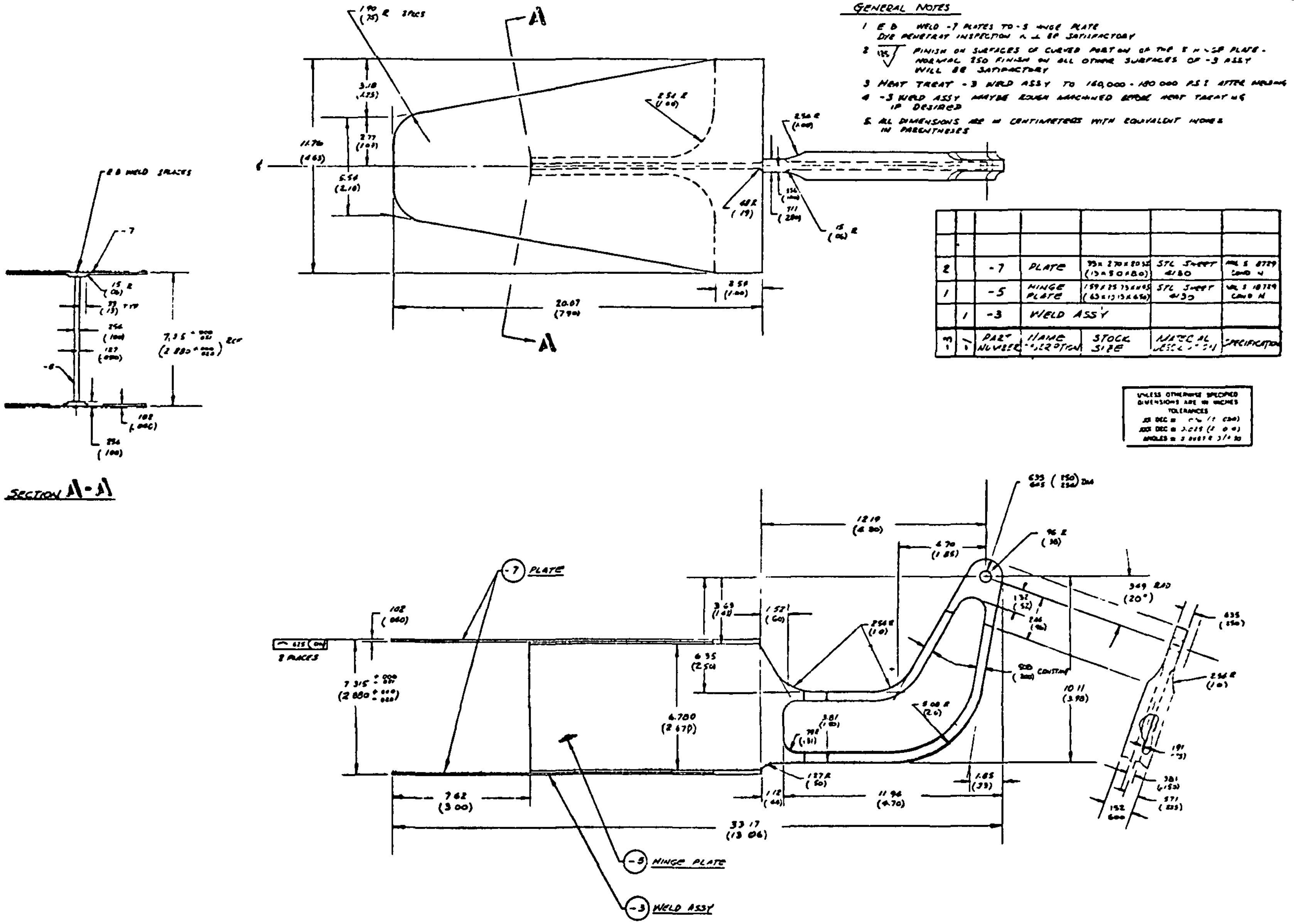

Figure 12. Door hinge (IT42861)

The part of the hinge fitting that is bonded into the honeycomb core is a basic I-section. The web provides the shear area required to transfer the load through the FM 40 foaming adhesive into the core. The flanges provide the shear transfer areas for the couple originating at the hinge pivot point to transmit this load into the face sheets through the Metlbond 329 adhesive. Flanges are tapered and the web is undercut to minimize high stress concentrations at the skin line.

The five 7075 aluminum latch fittings (fig. 13) are similar to the Shuttle orbiter design. They are bolted with high-strength blind bolts to an aluminum insert bonded into the honeycomb core. The aluminum insert, also shown in fig. 13, is a basic I-section similar to the hinge fitting and transfers the shear and bending loads resulting from the latch mechanism. Its flanges are also tapered to provide flexibility and reduce high stress concentrations at the skin line. The center panel column support fittings (fig. 14) are made of 7075 aluminum and attached to the aluminum inserts with high-strength blind bolts. The 7075 aluminum insert (fig. 15) is designed similarly to the other inserts. It is basically an intricately machined fitting shaped like two back-to-back channels connected on one side by a thin flange. The channel webs are sized to provide sufficient shear area to transfer shear loads into the honeycomb core through the FM40 foaming adhesive. Like the other inserts, the web is undercut and the flanges are tapered to reduce mismatch of stiffnesses between the honeycomb core and the metal inserts.

Eighteen TPS support links are fastened to the edge of the door with special machined fittings bonded and mechanically fastened to the edge support channels. The TPS is also supported in eight places in the center portion of the door by inserts bonded into the core and reinforced with local graphite/epoxy doublers.

The door actuating load comes from the two columns, which are attached to the column fittings on the door. One fitting is located at the leading edge, and the other is located two-thirds of the way back. At the leading edge, the door apparently has less effective width in resisting bending due to conditon B loading. For this reason, the doubler under the column fittings is extended for the entire span of the door (from hinge to latch).

The estimated full-size door weight is 62.36 kg (137.68 lb) for a 15.8-percent weight saving over the all-aluminum design. It is noted that the above weight and weight saving are slightly different from those quoted in reference 1, which were based on the use of FM404 as the foaming adhesive. The 62.36-kg (137.68-lb) door weight is less than that quoted on page 12 (74.8 kg [164.8-lb]), which was determined for a preliminary design. The difference is primarily due to the designs of the core inserts.

Door sector design. —The test door sector (fig. 16) was designed to provide a realistic subscale test of the full-size door design for the four design conditions. The door had two hinge fittings made with 4130 steel, instead of the titanium called for on the full-size door, to save on the cost of material and machining. The door also had two latch fittings, two latch fitting inserts, a center fitting insert, and a center strut fitting. The door was 7.62 cm (3.00 in.) thick, 83.18 cm (32.75 in.) wide, and 140.03 cm (55.13 in.) long. The graphite/epoxy laminated skin, channels, clips, and doublers were identical to the full-size door design.

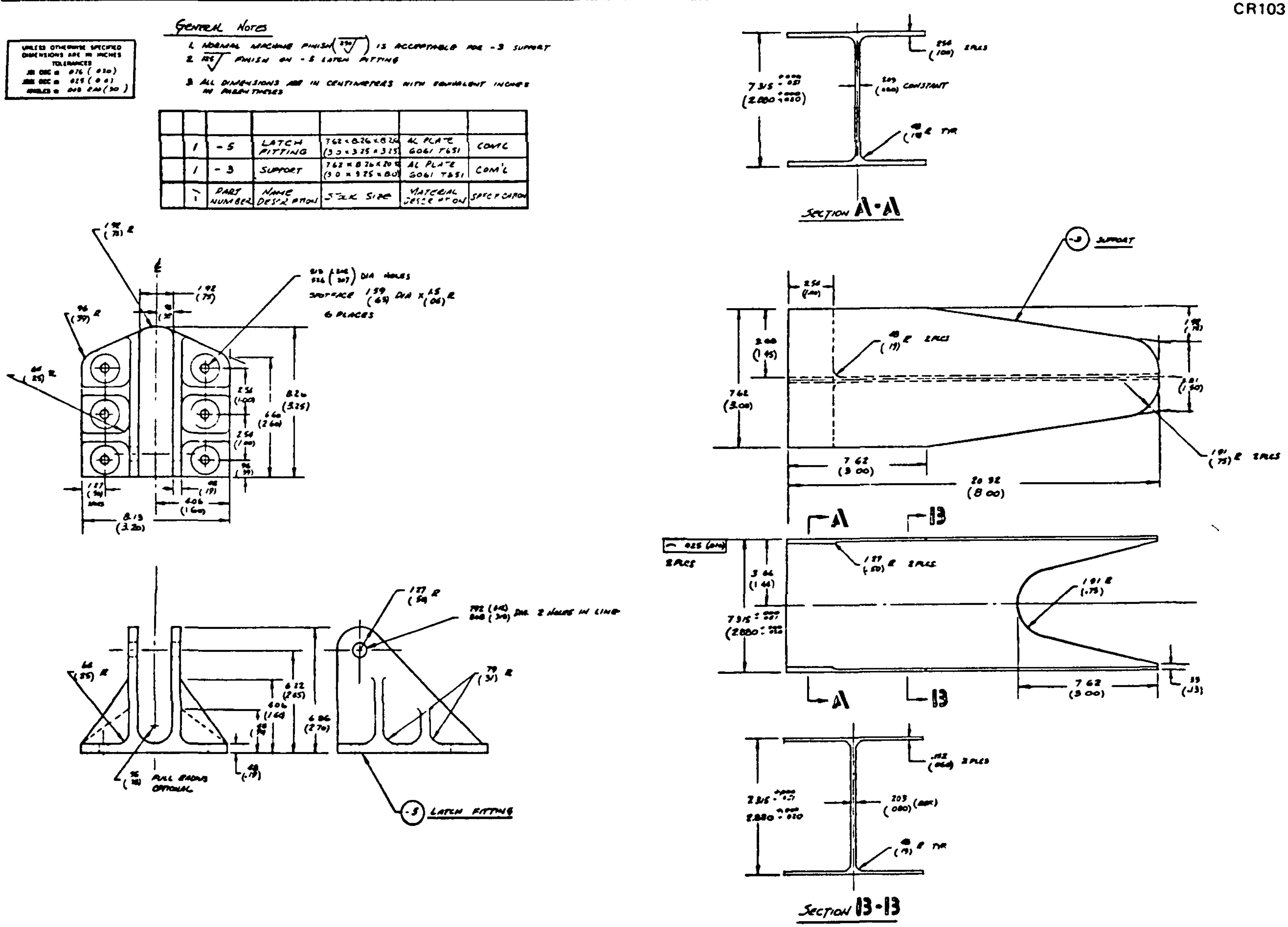

Figure 13. Door latch and support fitting (IT 42862)

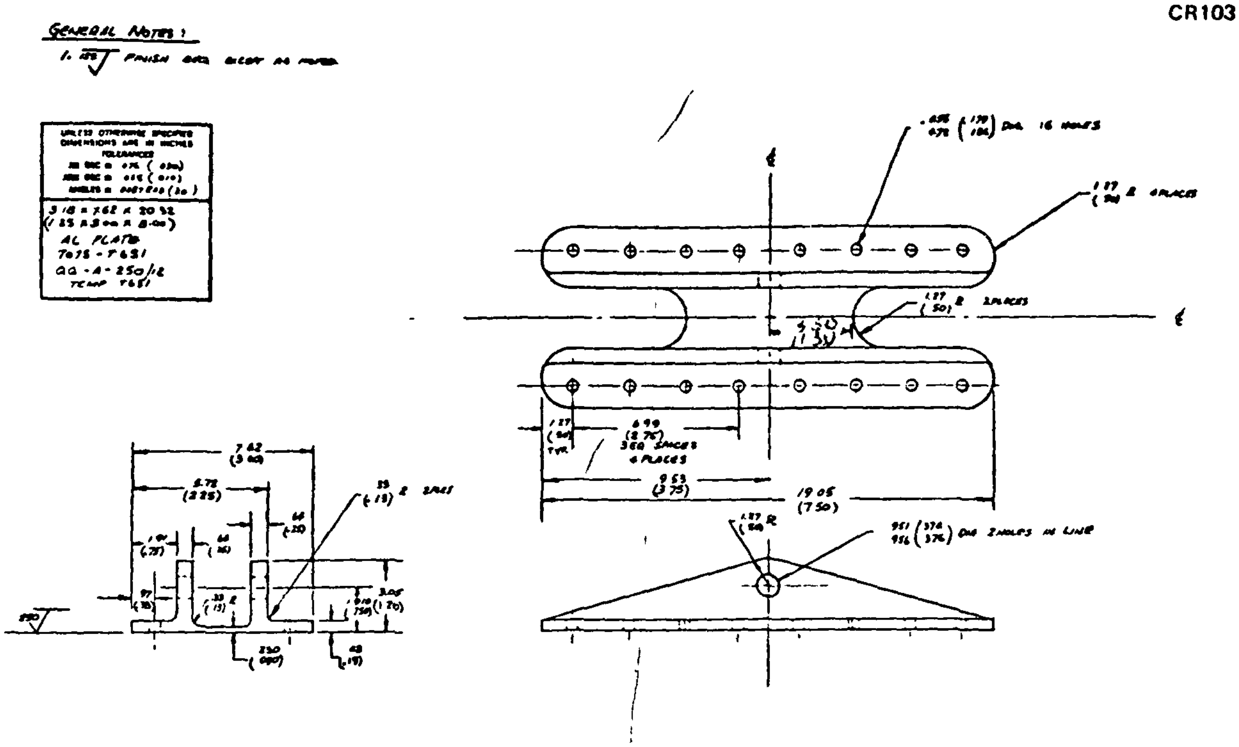

Figure 14. Door center fitting (1T42860)

Beam and column design. —The beam and column configurations were designed during the first part of phase I and were therefore aimed at the application of selective reinforcement of the titanium base structure with boron/epoxy strips. During the course of the program, it was realized that there was no appreciable weight saving to be gained with the hybrid design for these components, as indicated in the weight comparison shown in table 3; however, fabrication of the column was nearly completed when a decision was made to eliminate the boron/epoxy laminates from these components. The column, therefore, had the boron/epoxy reinforcement, but the beam was revised to eliminate the boron/epoxy.

Pivot beam design: The 6Al-4V titanium beam (fig. 17) was designed to transfer the actuator load to open the door and also to resist the airloads when the door is open. The beam was designed as a tapered I-beam with 0.381-cm (0.150-in.)-thick flanges and 0.254-cm (0.10-in.)-thick webs. The flanges were sized by the compression buckling loads resulting from the loads introduced at the three pivot points. The web thickness was determined by the minimum thickness required to machine without expensive backup web support. The large clevises resulted from the requirement to provide room to install pivot bearings similar to a production beam. Since the beam was not required to open and close the door during the structural testing of this program, regular AN bolts were installed at the three pivot points instead of hollow pivot bolts. The actual beam weight was 2.60 kg (5.72 lb).

Connecting column design: The column is the structural member through which actuation force is applied to the door panel. The material

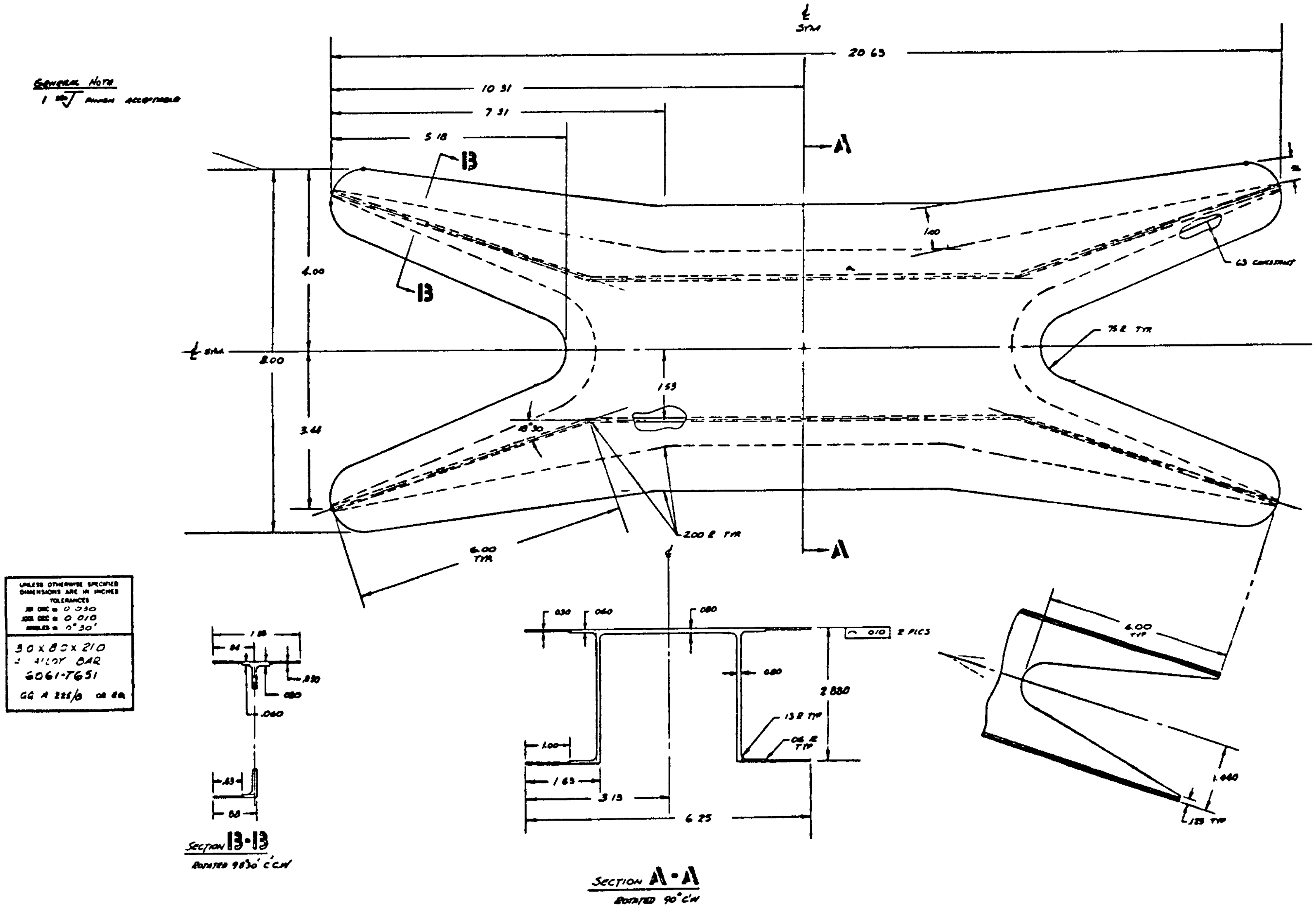

Figure 15. Door inner center support (IT42859)

TABLE 3

ESTIMATED WEIGHT OF MLDGA COMPONENTS—
BEAM AND COLUMN

MLGDA component	Estimated weight				Percent weight change
	All titanium		B/Ep-Ti		
	kg	(lbm)	kg	(lbm)	
Beam					
Hinges	0.98	(2.15)	0.95	(2.10)	2.5
Webs	0.43	(0.94)	0.43	(0.94)	0
Flanges	1.06	(2.34)	0.79	(1.75)	25.0
Adhesive	-	-	0.02	(0.04)	-
Total beam weight	2.47	(5.43)	2.19	(4.83)	11.2
Column					
Hinges	0.11	(0.24)	0.11	(0.24)	0
I-section	0.18	(0.39)	0.13	(0.29)	25.6
Adhesive	-	-	0.01	(0.01)	
Total column weight	0.29	(0.63)	0.25	(0.54)	14.2

for the column was Ti-6Al-4V titanium bar stock. The column was machined into an I-section member with a clevis at each end. The flanges of the I-beam were made thinner by machining to allow the addition of unidirectional boron/epoxy reinforcing strips, as shown in figure 18.

As indicated previously, the weight saving on this part was found to be insignificant. However, the machining on the column had advanced to the point that the recess for the B/Ep was already made when the decision not to use composite reinforcement was reached. Hence, three columns were fabricated with B/Ep reinforcement.

Analysis of MLGDA components. — The detailed stress analysis of the structural components in the main landing gear assembly was documented in reference 1. It was found that all the components were structurally adequate for the loadings specified in the four design conditions. A summary of the margins of safety is presented in table 4.

Development testing. —The objectives of the development testing on small-scale specimens were (1) to verify design concepts utilized in the

Figure 16. MLGDA graphite/epoxy test door (IT43113)

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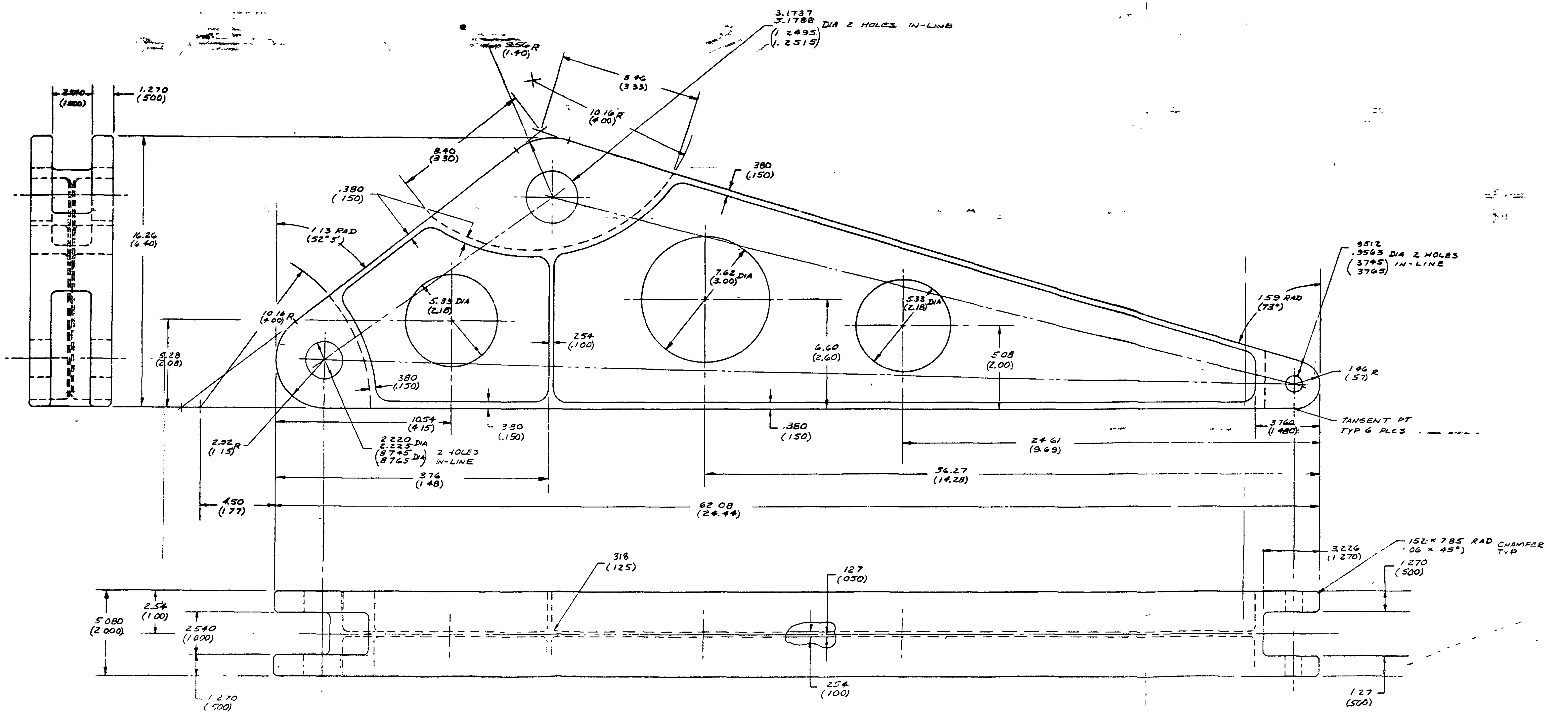
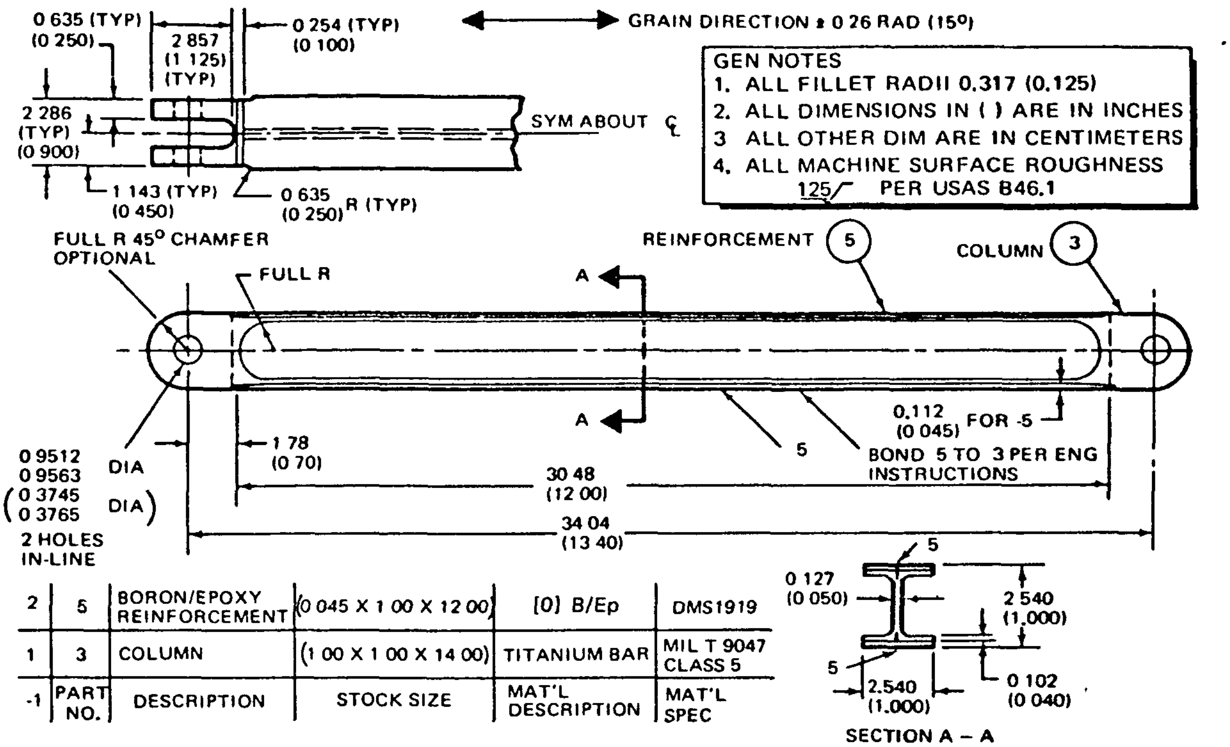


Figure 17 MLGDA beam (IT 43366)



2	5	BORON/EPOXY REINFORCEMENT	(0 045 X 1 00 X 12 00)	[0] B/Ep	DMS1919
1	3	COLUMN	(1 00 X 1 00 X 14 00)	TITANIUM BAR	MIL T 9047 CLASS 5
-1	PART NO.	DESCRIPTION	STOCK SIZE	MAT'L DESCRIPTION	MAT'L SPEC

Figure 18 Boron/epoxy-reinforced MLGDA column (IT42088)

prototype door sector and (2) to verify manufacturing procedures to be used in the fabrication of the door. For the former, fatigue tests and a bending test were performed on sandwich specimens; for the latter, adhesive joint and fasteners tests were made.

Fatigue tests of sandwich beam· Three sandwich beams (fig. 19) were subjected to flexural tests under cyclic loads. The first specimen underwent 500 cycles at an equivalent load of 1,780 N (400 lb) (which was slightly more severe than the required pressure per cycle in design condition D) as a conservative measure, causing facing stresses of 125 MN/m^2 (18,200 psi). The second specimen was tested under the same load up to 10,000 cycles. The third specimen was tested at 50-percent and 88-percent higher load, with 5,000 cycles at each load level. Visual inspection did not reveal any failure in the beam. Ultrasonic pulse echo tests conducted on both faces of the beam before and after the tests did not show signs of debonding of adhesive from the faces. However, the ultrasonic through-transmission test technique was not successful in detecting either failures in the core or at the junction between the core and the adhesive fillets. Subsequently, the third specimen was sectioned and found to be free of such failures. It was concluded that the Metlbond 329 adhesive was more than adequate for application under the cyclic pressure loadings defined in design condition D.

Static test of sandwich panel· The 0.191 by 0.382 m (7.5 by 15.0 in.) sandwich panel shown in figure 20 was tested as a beam supported at the two short edges for the purpose of evaluating the design concepts of the core insert and the edge closure channel. The support point at each end aligned

TABLE 4

SUMMARY OF MARGINS OF SAFETY

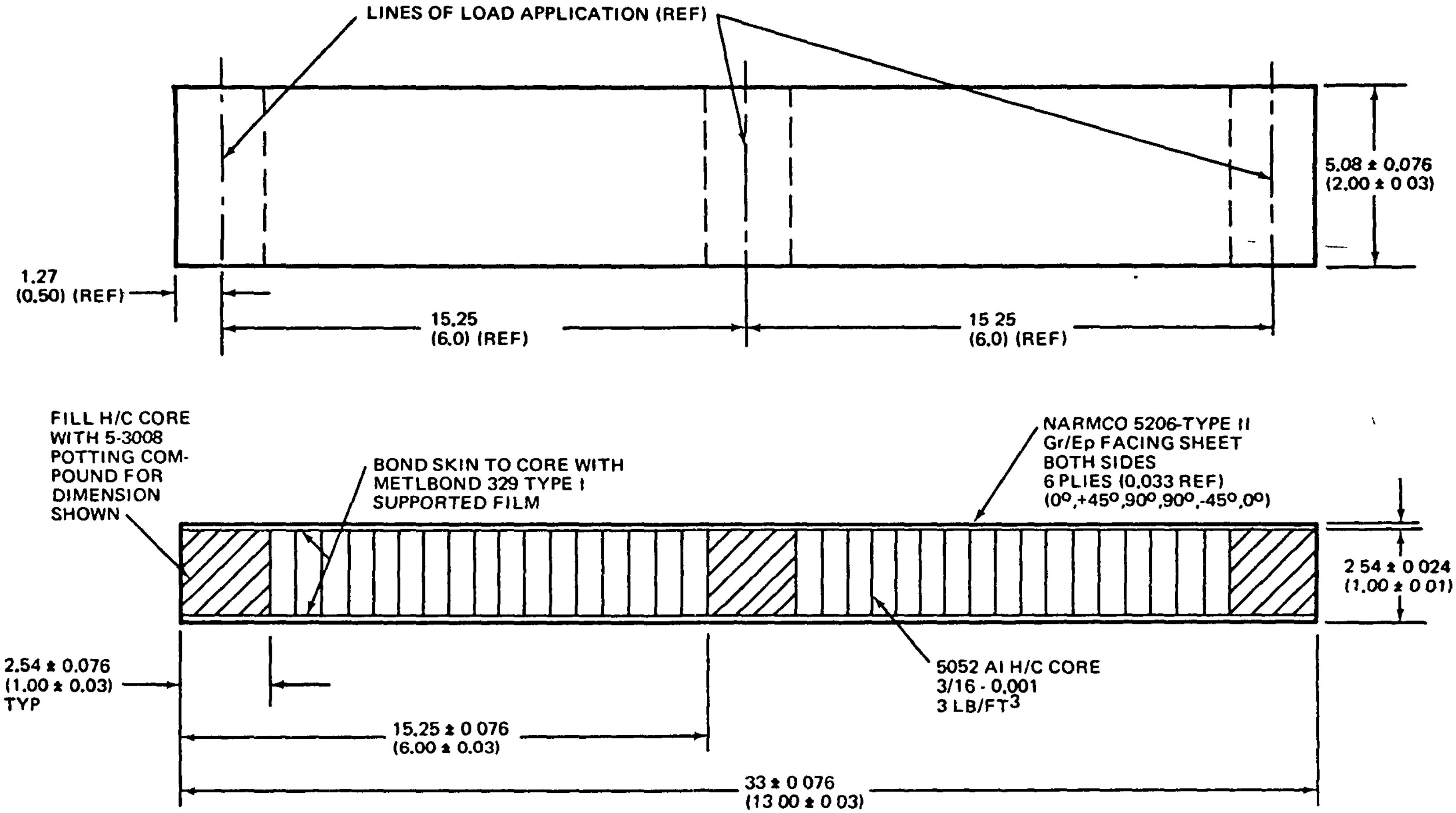
Component	Critical areas	Design condition	Analyzed for	Margin of safety
Gr/Ep door	Skin	A	Bending (tensile stress)	+0.17
	Core insert at column fitting	B	Core shear	+ .73
	Core insert at hinge fitting	B	Core shear	+ .85
	Skin	C	Bending (tensile)	+ .64
	Skin	D	Bending (tensile)	Large*
Ti beam	Upper flange	C	Local crippling	+ .41
B/Ep-Ti column	I-section	C	Interaction between crippling and Euler buckling	+ .14

*Margin of safety greater than 1.0 considered to be large.

with the web of the edge closure. The beam was loaded with a static concentrated force at the center. This centrally applied load reached a value of 29, 300 N (6, 590 lb) when the beam failed in core shear.

The failure load was much higher than the predicted value of 9, 400 N (2, 120 lb) based on minimum core shear strength. The high test value could be due to either higher-than-minimum shear strength of the core or the strain energy in bending of the graphite skins, or both. Since all core inserts in the full-size Gr/Ep door and in the test door sector were also designed on the basis of minimum shear strength of the core, results of this one test indicated that these inserts were more than adequate.

The line load at the edge closure channel was found to be 77.0 kN/m (440 lb/in.), corresponding to the 6, 590-lb failure load at the center. This load compared favorably with the actual design load of 58.0 kN/m



NOTE DIMENSIONS IN cm (IN)

Figure 19. Fatigue test specimen

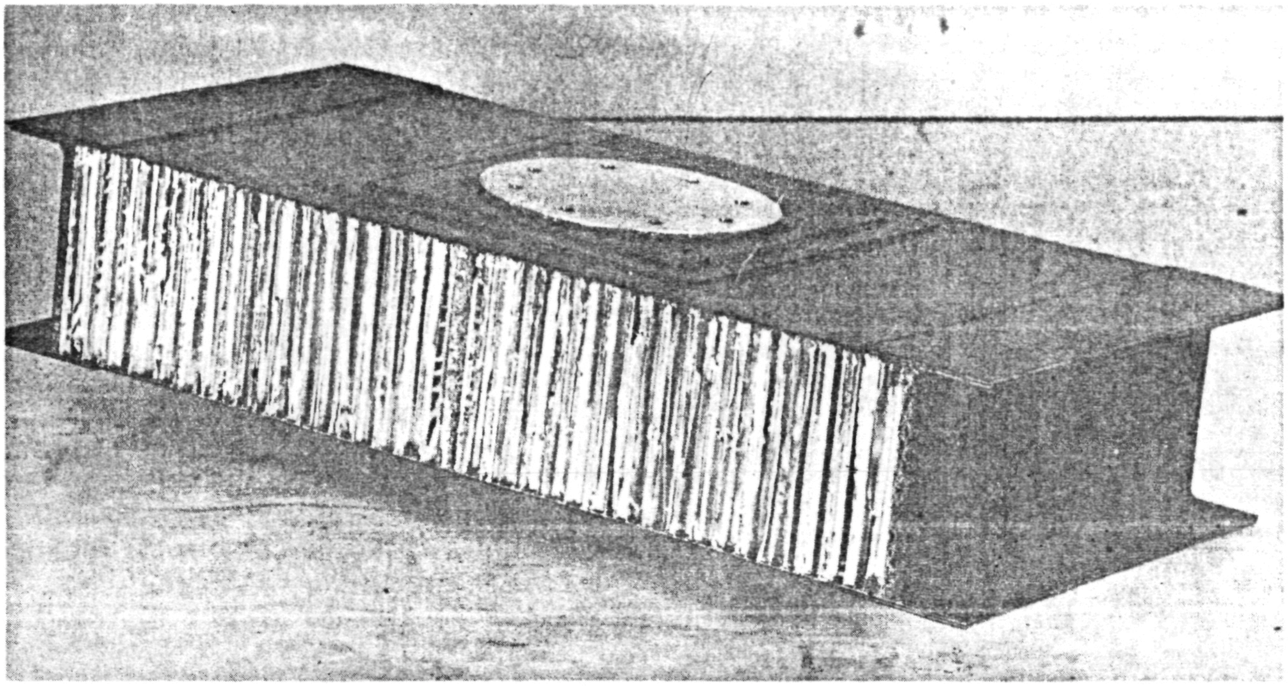


Figure 20. Completed sandwich panel

(332 lb/in.) for the full-size door. An inspection of the edge closure channel, the FM 40 foaming adhesive, and the adjacent honeycomb core cells revealed no damage due to shear or any other cause.

It was concluded that this test demonstrated the adequacy of the design concepts for the core insert and the edge closure.

Adhesive joint test: In order to determine the effects of the residual thermal stresses on the bonded joint between the inserts and the skins during fabrication of the door, a 0.508-m (20-in.) long aluminum channel was fabricated. The channel was designed to simulate the stiffness of the center insert. A six-ply [0/45/90/90/-45/0] graphite/epoxy strip was bonded to one of the flanges of the channel with Metlbond 329 following the normal procedures required for this adhesive.

After the adhesive was cured and the bonded channel was cooled to room temperature, the adhesive bond was inspected under the microscope, and no cracking was noted. The channel was then chilled to 219°K (-65°F). Again the bond was intact.

The results of this simple test indicated that residual stresses in the bond due to fabrication do not cause cracking in the adhesive or debonding of the graphite/epoxy from the aluminum.

Mechanical fastener evaluation: Before any of the blind fasteners

selected for installation in the test door sector and the 19.1- by 38.2-cm (7.5- by 15-in.) sandwich panel were installed, an investigation was conducted to determine if there would be any problems arising from use of these fasteners. Particular concerns were whether there would be any interference by the honeycomb in the proper forming of the retainer head, and that no crushing or cracking occur in the composite.

Sandwich specimens were prepared consisting of a graphite/epoxy skin bonded to an aluminum sheet, which in turn was attached to a segment of honeycomb core with foaming adhesive. On these specimens, which were representative of a typical door section at the insert locations, 10 blind bolts and 10 blind rivets were installed. After installation, a visual inspection was made by cutting away the honeycomb to view the formed head and inspect for crushing or cracking of the composite. All fasteners appeared to be installed perfectly without any interference from either the foaming adhesive or the honeycomb. No deformation of any kind was observed in the composite. Therefore, blind fastener application was considered feasible for the Gr/Ep door design.

FABRICATION OF MAIN LANDING GEAR DOOR COMPONENTS

General Discussion

This section presents the highlights of fabrication of the structural components in the test door sector assembly. Emphasis was placed on the graphite/epoxy door sector. A more detailed description of the fabrication procedures and quality controls was documented in reference 2.

Column (IT42088)

The titanium columns were grit-blasted on the bonding surfaces and were then chemically cleaned and etched. BR-400 adhesive primer was applied to the prepared flange surfaces, air-dried, and oven-cured.

A boron/epoxy laminate was fabricated 19 by 30.5 cm (7.5 by 12 in.) by nine plies unidirectional in the long 30.5-cm (12-in.) direction. After curing, the laminate was cut into six strips 2.54 by 29 cm (1.0 by 11.750 in.).

The bonding surfaces of the strips were grit-blasted with white aluminum oxide and wiped clean with solvent MEK. BR-400 adhesive primer was applied to the cleaned surfaces, air-dried, and oven-cured.

The columns and boron/epoxy strips were assembled using FM-400 adhesive film, placed in a vacuum bag, and cured in an autoclave for 2 hr at 450°K (350°F) and 0.59 MN/m^2 (85 psi). These columns are shown in figure 21.

Individual and combined weights of the titanium columns and boron/epoxy composite laminates are recorded in table 5.

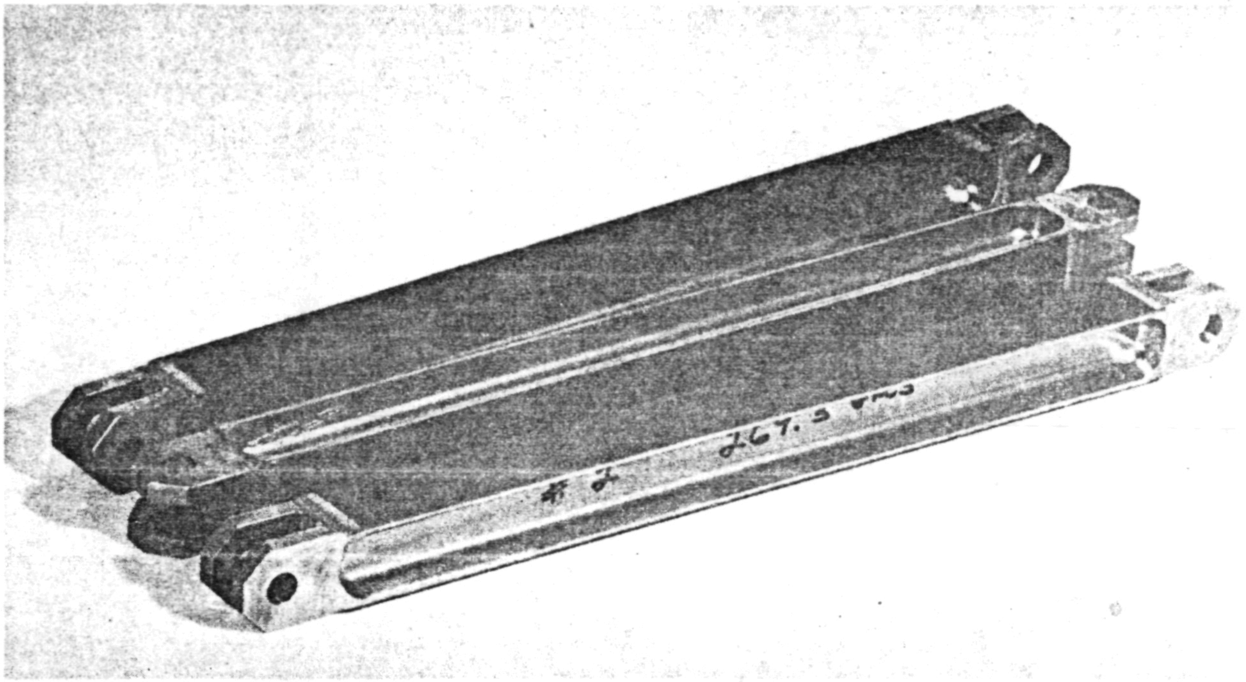


Figure 21. Titanium-boron/epoxy columns

TABLE 5

MLGDA COLUMN WEIGHT

Specimen no.	Weight of Ti column		Weight of boron/epoxy		Combined weight of hybrid		Weight of adhesives	
	kg	lbm	kg	lbm	kg	lbm	kg	lbm
1	0.221	0.486	0.034	0.075	0.260	0.572	0.0048	0.0011
2	0.228	0.502	0.034	0.075	0.269	0.592	0.0072	0.0016
3	0.218	0.479	0.034	0.075	0.258	0.568	0.0057	0.0013

Beam (IT42087)

As noted under "Beam and column design," the titanium beam was not fabricated with selective boron/epoxy reinforcement. Weights of these beams averaged about 2.6 kg (5.72 lb).

Door Test Sector (IT43113)

The major fabrication activity was involved in the layup, curing, assembling, and bonding of the door components.

Nonmetallic material selection. —Composite materials were selected based on phase I coupon testing and results of small-scale sandwich panel tests. As a result, Whittaker Corporation's 5206-II graphite/epoxy continuous tape, which qualifies to Douglas Aircraft Company Douglas material specification (DAC DMS) 1936B, was selected for the facings, edge closures, and closure clips, and all composite details were laid up using 7.62-cm (3-in.) wide prepreg tape.

Similarly, Whittaker Metlbond 329 was selected for bonding of the facings to the core, also on the basis of phase I testing. This material qualifies to DAC DMS 1808C.

American Cyanimid FM40 was selected as the foaming adhesive for splicing the core and joining the core inserts and edge closures. This material qualifies to DAC DMS 1808C.

Receiving quality control tests on graphite/epoxy prepreg. —Whittaker Corporation's 5206-II graphite/epoxy was procured (batch 362) and submitted for quality control testing in accordance with DMS 1936B. This batch satisfied all specification requirements and was used for fabrication of graphite/epoxy details.

Fabrication control. —Fabrication instructions and control were defined with Douglas Aircraft fabrication and control traveller (FACT) documents. These documents detailed the processing and in-process quality control steps, defined the sequence of operations, and recorded material batch and lot numbers. Changes made during processing and deviations were noted on the forms, and the final document became a permanent record of the component fabrication.

Tooling and fixtures. —

Bonding jig: The bonding jig is shown in figure 22. The purpose of this jig was to position and secure the metal inserts, core, and edge closures through the subassembly adhesive foaming operation, with the lid of the tool applying a uniform pressure to all details during curing of the foaming adhesive. The bonding jig was also used during the skin-to-core bonding operations. In the foaming operation, the function of the tool was to locate and maintain the position of the upper and lower facings on the core. In the latter operation, the lid was not used.

Also provided with this tooling were simple aluminum blocks with dimensions to match the internal dimensions of the graphite/epoxy closures. These blocks were used to support the edge closures, especially during the autoclave operation used to bond the facings and core subassembly.

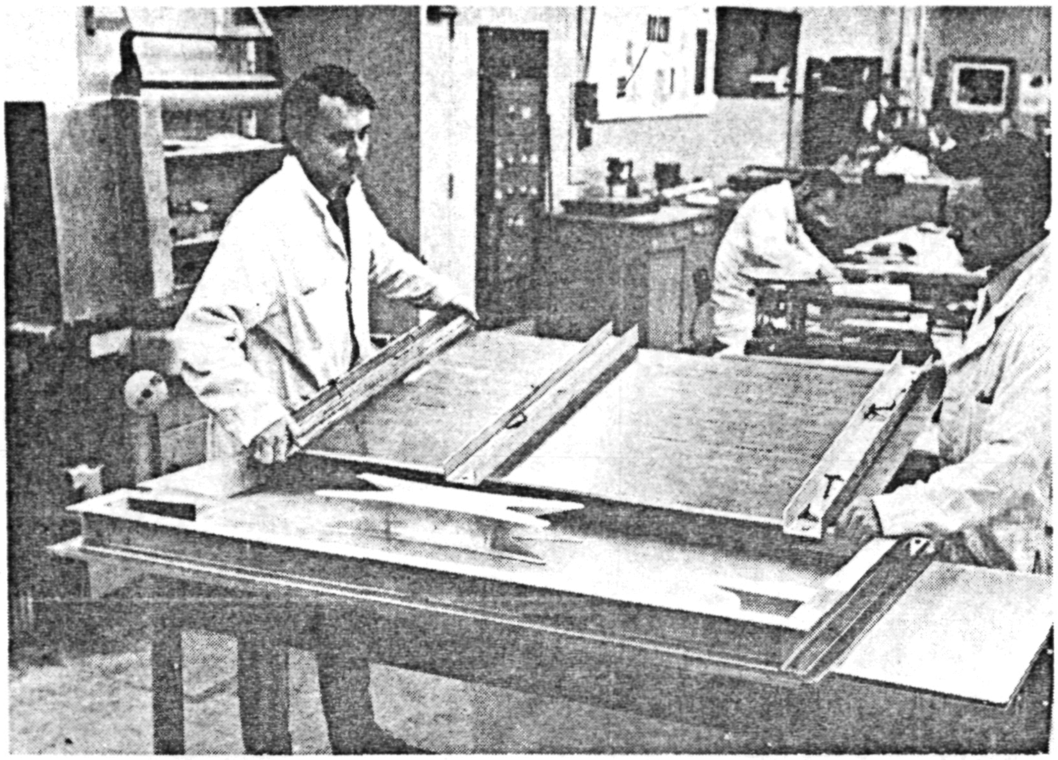


Figure 22. Bonding jig for core subassembly

Molds for door closing channels: Two male molds were fabricated for layup and cure of the graphite/epoxy edge closures. Web dimensions at the ends of the molds were reduced to allow the ends of the channel to match the internal dimensions of the mating metal inserts.

Autoclave bag: A butyl rubber envelope autoclave bag was molded for bonding of facings to the core subassembly. Internal dimensions of this bag were 5.08 cm (2 in.) deep, 122 cm (48 in.) wide, and approximately 267 cm (105 in.) long. These dimensions were oversize and were selected for the purpose of bagging the bonding fixture with sufficient clearance to prevent bridging on the sides and ends of the tool during the autoclave bonding cycle.

Mold clips: A steel male mold was used to make the -27 clips, as shown in figure 16. This was a right-angle mold with a 3.17-mm (0.127-in.) radius. This mold was of sufficient length to lay up and cure all -27 clips in one operation.

Fabrication of door test sector. —The sequence of fabrication operations is shown in figure 23. Dash numbers discussed herein can be located on figure 16.

Fabrication of -3 facings and doublers: The fabrication approach pursued was to lay up the facings and doublers integrally and cocure these laminates. Also, the doubler sets (e.g., -7 and -9, -15 and -17) were each considered as one doubler for layup purposes. Consequently, ten 12-ply doublers were

CR103

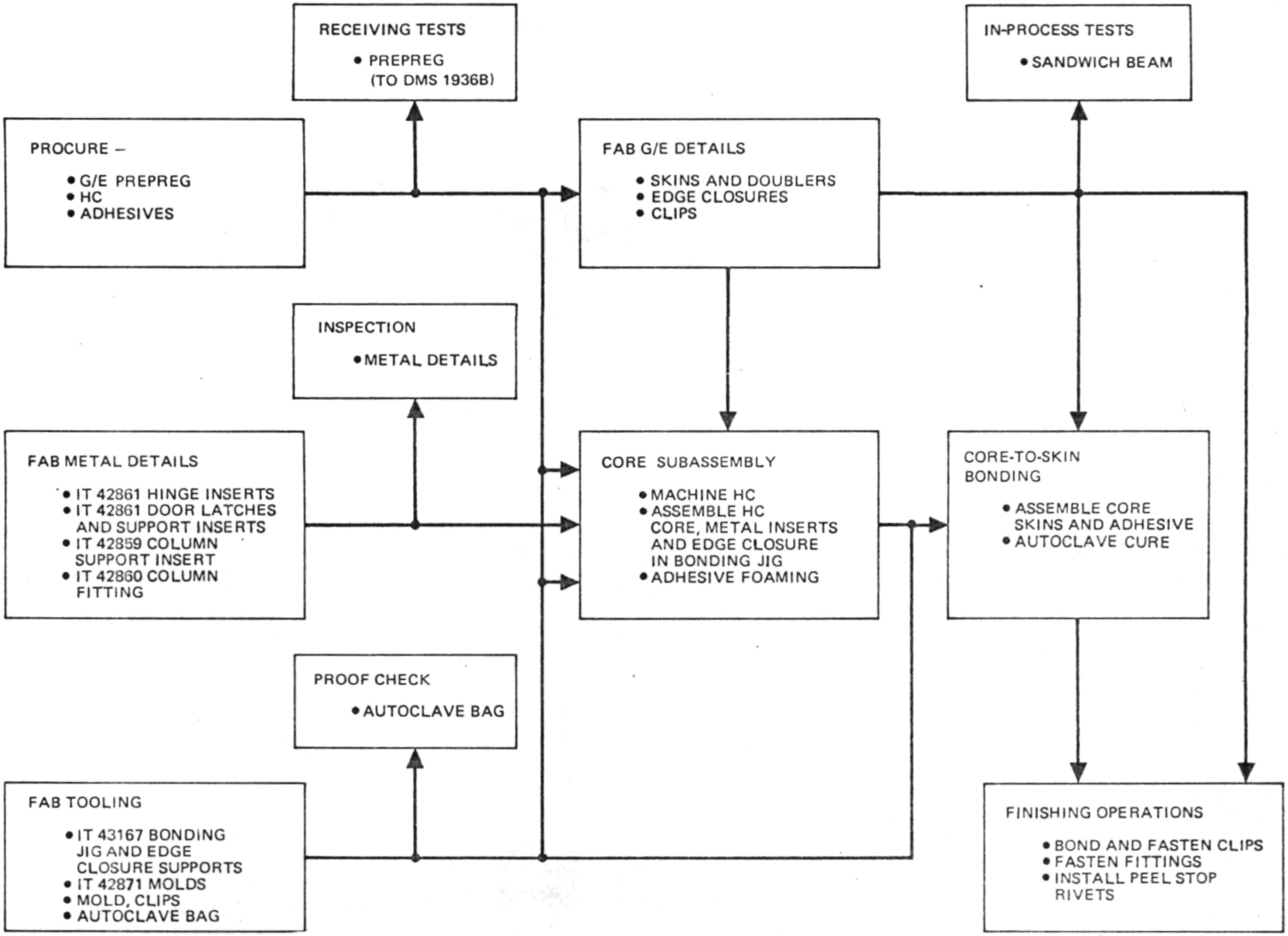


Figure 23. Flow of fabrication operations

laid up using the following fiber pattern: $[0°, +45°, 90°, 90°, -45°, 0°]_s$. Overage was provided for final trim on the length and in the extreme corner areas of all doublers except the -7 and -9 set, which was laid up net to dimensions. Aluminum templates were employed as layup aids for shaping the plies. After layup of the first doubler ply, each of the successive plies was staggered back approximately 2.54 mm (0.100 in.) around the periphery to provide a smooth transition with the skins. The last ply in each doubler set was laid up to the dimensions of the first ply. These doublers were stored in moisture-proof bags until layup of the skins was complete.

Two -3 skins were laid up with sufficient overage in length for trim and in width for obtaining in-process test specimens. These were six-ply skins with a fiber orientation of 0°, +45°, 90°, 90°, -45°, 0°. (The order of the +45° and -45° layers was reversed for the lower skin.)

Upon completion of the skin layup, the positions of the five doubler sets were determined on the skin in accordance with figure 16, and the doubler sets were installed on the skin. The skins with doublers were autoclave-cured under the following schedule:

1. One-half hour at 408°K (275°F) and 0.689 MN/m^2 (100 psi).

2. Two hours at 450°K (350°F) and 0.689 MN/m^2 (100 psi).

Full vacuum was maintained throughout the cure cycle.

The skins were trimmed to drawing dimensions, 140.03 cm (55.13 in.) in length and 83.18 cm (32.75 in.) in width. Also, test specimens were machined from the trim for in-process quality control testing (sandwich beam). One of the completed skins is shown in figure 24.

Fabrication of edge closure channels: Fiber orientation for the edge closure channels was +45°, -45°, 90°, 90°, -45°, +45° on the webs of the channels and 0°, +45°, -45°, 0°, 90°, 90°, 0°, -45°, +45°, 0° on the channel legs.

A typical layup and curing cycle on the IT42871 mold (-1 configuration, shown in ref. 2) produced a -21 channel and either two -23 channels or two -25 channels. Therefore, two layup and curing operations were required to produce all of these channels. Two layup and curing operations on the -501 mold produced two -19 channels.

The autoclave curing procedure was the same as that described for curing of the skins.

Figure 25 shows the completed edge closure channels.

Fabrication of -27 clips: Fiber orientation for these clips was 0°, +45°, -45°, 0°, 90°, 90°, 0°, -45°, +45°. One layup on the steel angle mold produced sufficient stock to machine 12 clips. To produce these clips, a layup approximately 76.2 cm (30 in.) long was required. Autoclave curing was the

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Figure 24. Completed skin (-3)

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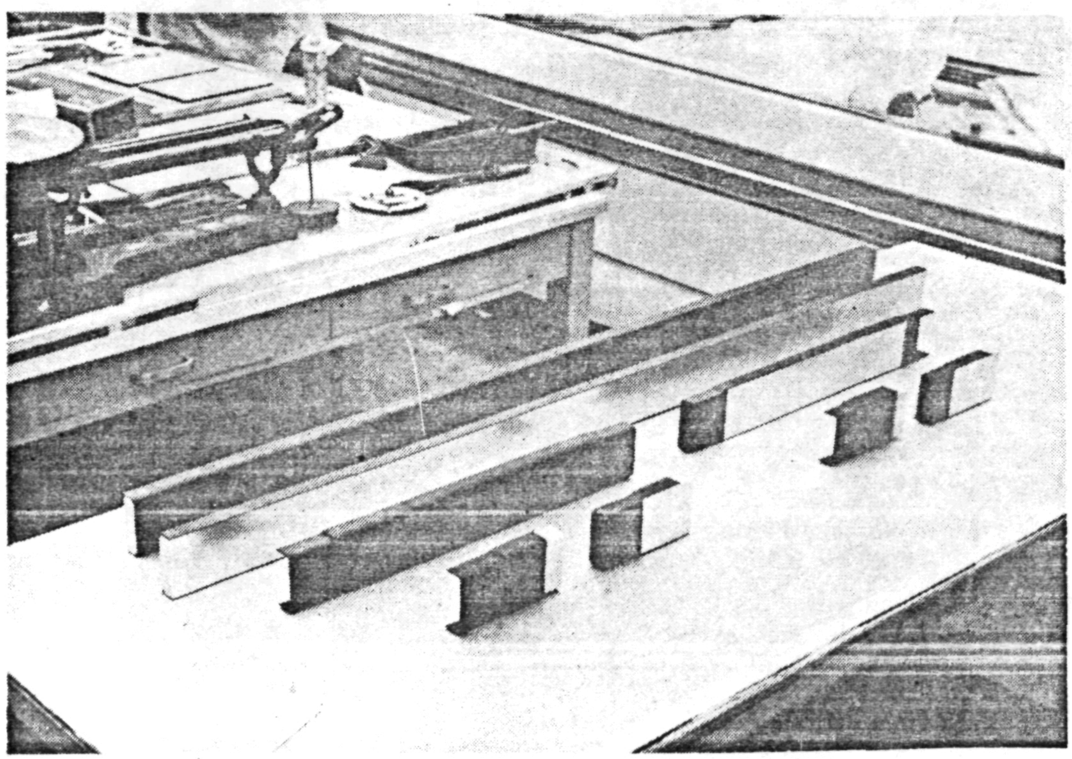

Figure 25. Completed channel section on aluminum support blocks

same as described for the skins. The clips were machined to dimensions, including a height of 6.05 cm (2.38 in.) and a leg length of 2.18 cm (0.86 in.).

Preparation of aluminum honeycomb: Perforated 5052 aluminum honeycomb 0.477 cm (3/16 in.) cell -0.0025 cm (-0.001 in.) 49.7 kg/cm^3 (3.1 lb/ft^3), was used for the door sector. Depth of the core was 7.33 cm (2.88 in.). A dimensionless Mylar template was furnished for machining the core, and this provided for machining the core into two large L-shaped pieces, together with small center sections to fit between the webs of the center insert. This layout pattern is shown in figure 26.

Honeycomb core-inserts-edge closure subassembly: The metal inserts integrated into the core subassembly are illustrated as follows:

1. Aluminum center insert, figure 27.

2. Aluminum latch inserts, figure 28.

3. Steer hinge inserts, figure 29.

The metal inserts were located according to drawing IT43113 (fig. 16). The 6.35-mm (0.250-in.) diameter tooling holes were drilled through the upper flanges of all inserts to match the hole pattern of the bonding jig lid. The inserts were fitted together with the core sections and the edge closure channels, and were located in the bonding jig to determine fit. Then the details were removed and prepared for the adhesive foaming operation.

The FM40 foaming adhesive was applied to the details as follows:

1. One layer on the webs of the edge closures.

2. One layer on all web surfaces of the metal inserts.

3. One layer at the splice areas of the honeycomb sections.

4. One layer on the flange locations of the core where the inserts were to be installed. This layer was pressed into the cells with a hot iron.

Metlbond 329 adhesive was applied at the ends onto the faying surfaces of the -19, -23, and -25 channels for bonding to the interior flanges of the metal inserts.

The four small sections of core were assembled with the center insert. The two large core sections were assembled with the center insert and joined together. The two latch inserts and two hinge inserts were fitted into the core. This assembly was then placed in the bonding jig. A sheet of 1.58-mm (0.062-in.) thick silicone rubber was placed on the assembly to apply a uniform pressure to the core and inserts from the lid of the bonding jig.

With one side rail and both end rails of the bonding jig removed, the two -21 channels were installed on their support blocks in the bonding jig. The

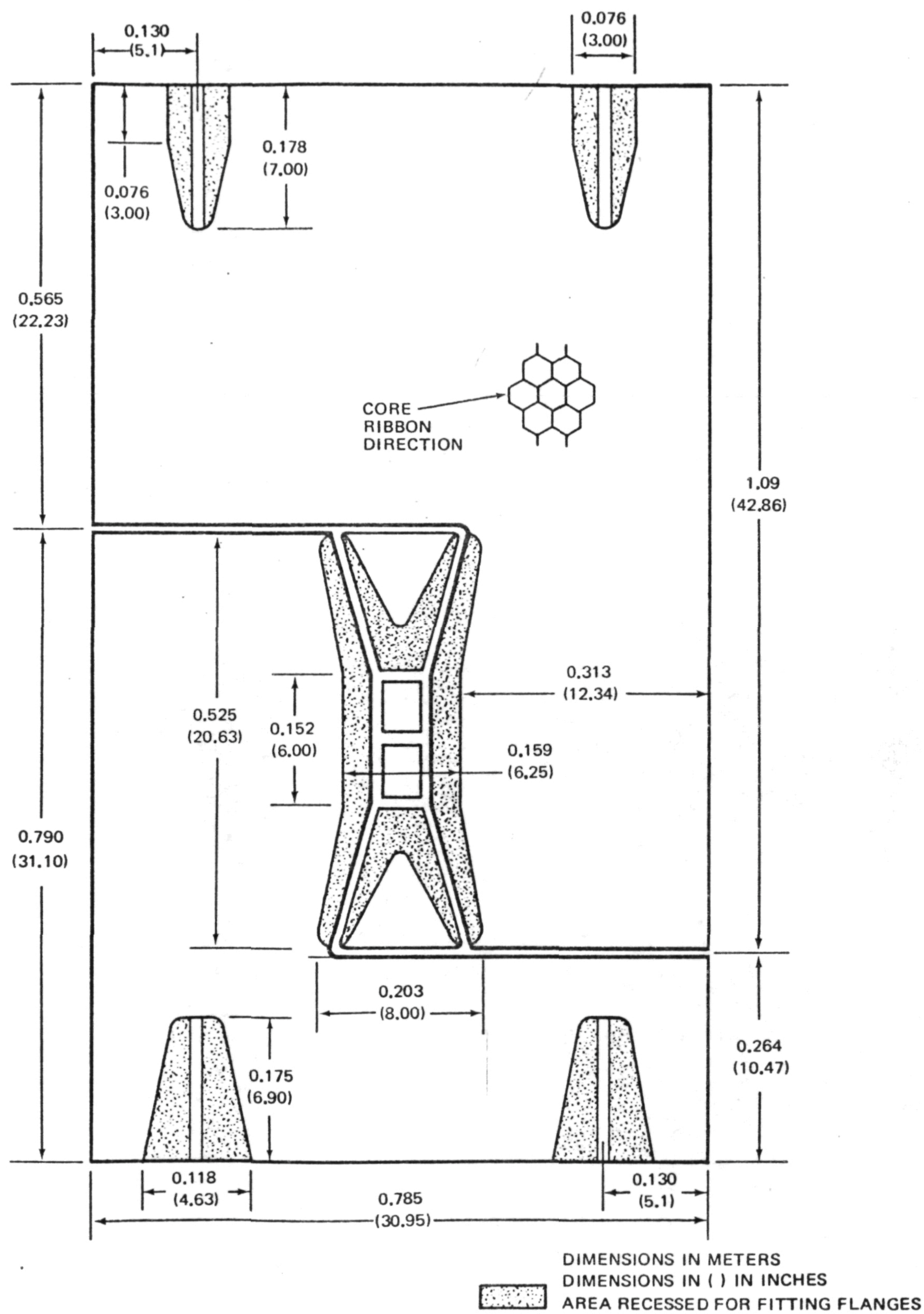

Figure 26. Layout for machining honeycomb core

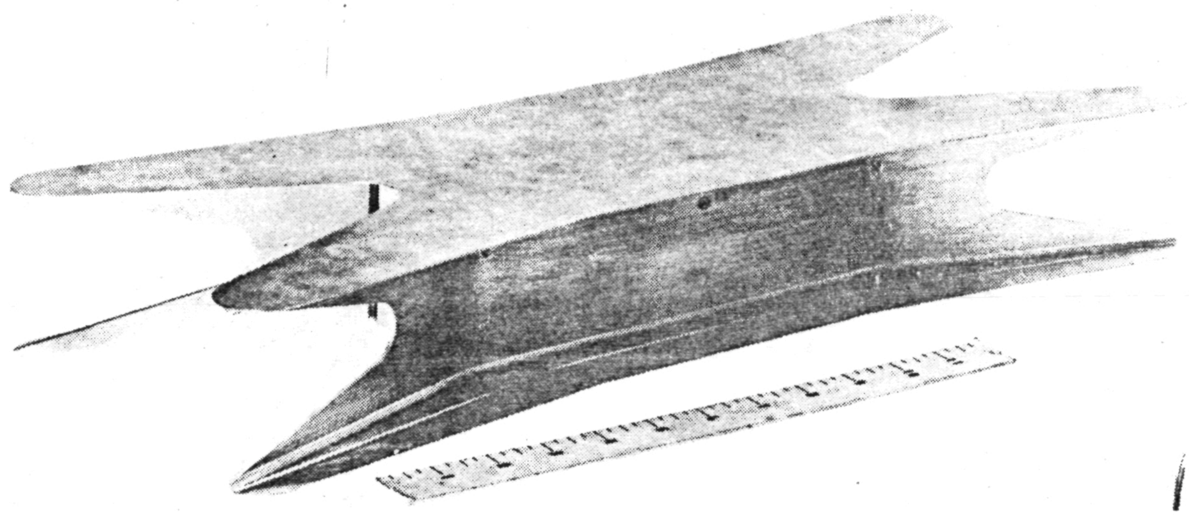

Figure 27. Aluminum center insert

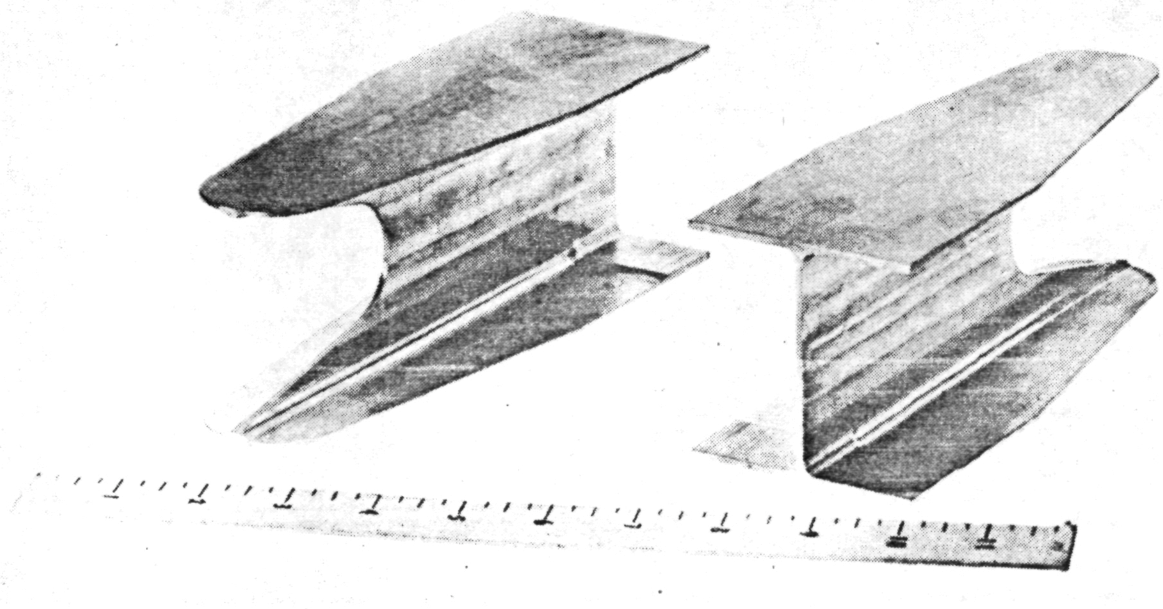

Figure 28. Aluminum latch inserts

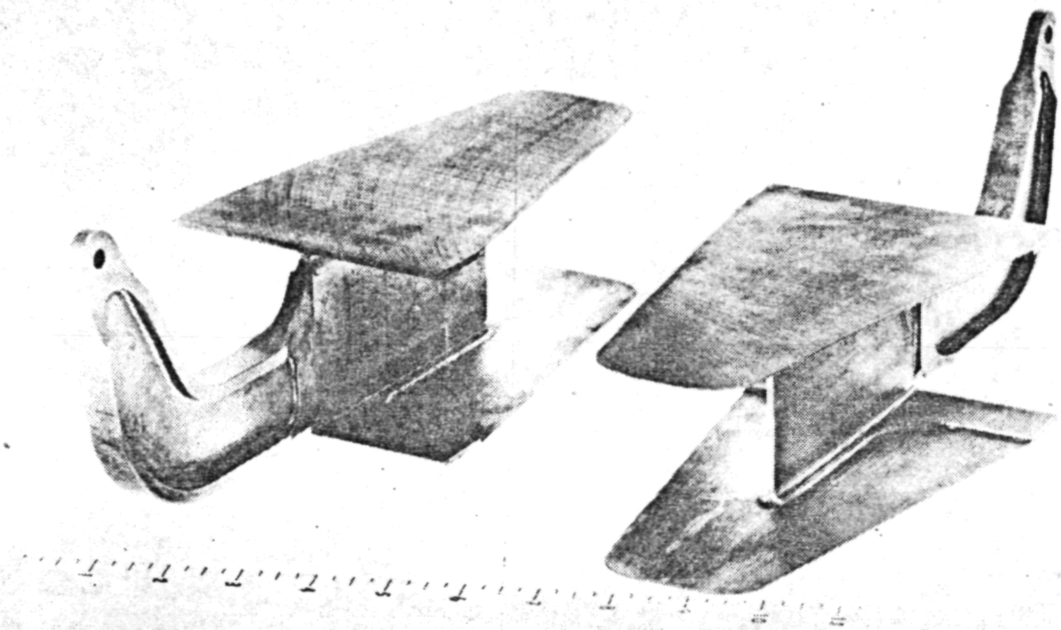

Figure 29. Steel hinge inserts

side rail of the bonding jig was then replaced. The -23 and -25 channels, located on their support blocks, were then placed in the bonding jig. The lid of the bonding jig was lowered and, by gently moving the core, the tooling holes in the flanges of the inserts were aligned with the holes in the lid of the bonding jig. The tooling pins were then located in place through the lid and into the inserts. The -19 channels were then located. The end rails of the bonding jig were replaced.

The bonding jig lid was then bolted to the side rails of the jig. The assembled jig is shown in figure 30. The FM-40 foaming adhesive was oven-cured 1 hr at 450°K (350°F). The part was cooled to 325°K (125°F) and removed from the oven. The completed core subassembly is shown in figure 31.

Bonding of facings to core subassembly: Operations involved in bonding the skins and core included the following:

1. The bonding surfaces of the upper and lower -3 skins were grit-blasted.

2. A sheet of 1.59-mm (0.062-in.) thick silicone rubber was cut to fit the bottom of the bonding jig. A second sheet of silicone rubber, also 1.59 mm (0.62 in.) thick, was tailored to fit those areas of the skin that did not contain doublers. The purpose of these rubber sheets was to provide a complete and uniform support to the lower skin during bonding.

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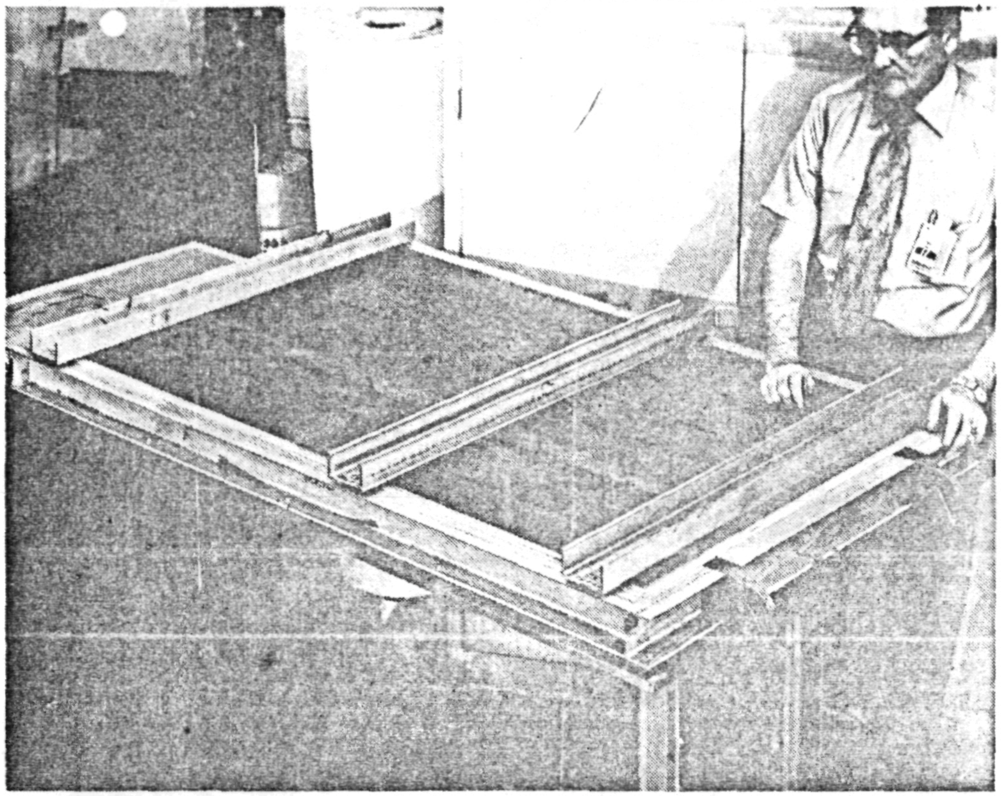

Figure 30. Bonding jig with core subassembly

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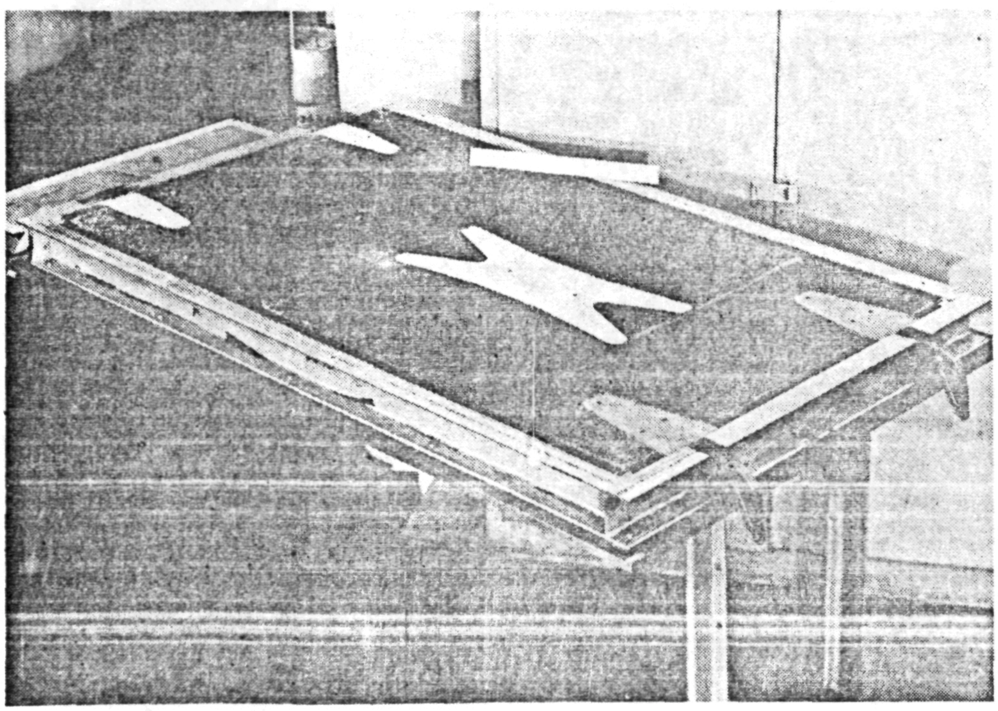

Figure 31. Core subassembly after adhesive foaming operation

3. A ply of Metlbond 329 adhesive was applied to the bonding surface of the lower skin. This skin was then placed in the bonding jig with the doublers down in contact with the silicone rubber.

4. The core subassembly was lowered into the bonding jig.

5. A ply of Metlbond 329 adhesive was placed over the entire core subassembly.

6. The upper skin was located on the assembly with the doublers up.

7. The assembly was prepared for bagging, and a butyl rubber bag was installed on the bonding jig and assembly.

8. The bonding cycle was 90 min at 450 °K (350 °F), 0.207 MN/m^2 (30 psig), and 127 mm (5 in.) Hg vacuum.

9. The assembly was cooled to 325 K°(125°F) under pressure before removal.

Figure 32 shows the door after removal from the bonding jig.

Finishing operations: The IT42860 column fitting (fig. 14) and two IT42862 latch fittings (fig. 13) were located in place on the door and attached to their respective inserts using lock bolts.

Cherry rivets were installed as "peel stoppers" around the border of the door. The -27 clips were attached with rivets at the four corners of the door and at the webs of the inserts and edge closures.

The completed door is shown in figure 33, together with the column and beam.

In-process quality control testing. —Four sandwich beam specimens were fabricated using panels from the trim sections of the upper and lower -3 skins. Two specimens were tested with the graphite/epoxy facing sheets on the tension side of the beam, and two specimens were tested with the graphite/epoxy on the compression side of the beam. Results are shown in table 2. Both tensile and compression properties were acceptable, based on the testing performed.

Weights of mid-sector door details. —A log of weights was maintained during the fabrication of the door panel. The purposes were to compare actual and predicted weights and to determine major areas of growth in any program for reducing the weights of components. The weights recorded are shown in table 6.

The final weight of the door with fittings of 15.314 kg (33.76 lb) was very close to the estimated weight of 15.41 kg (33.92 lb).

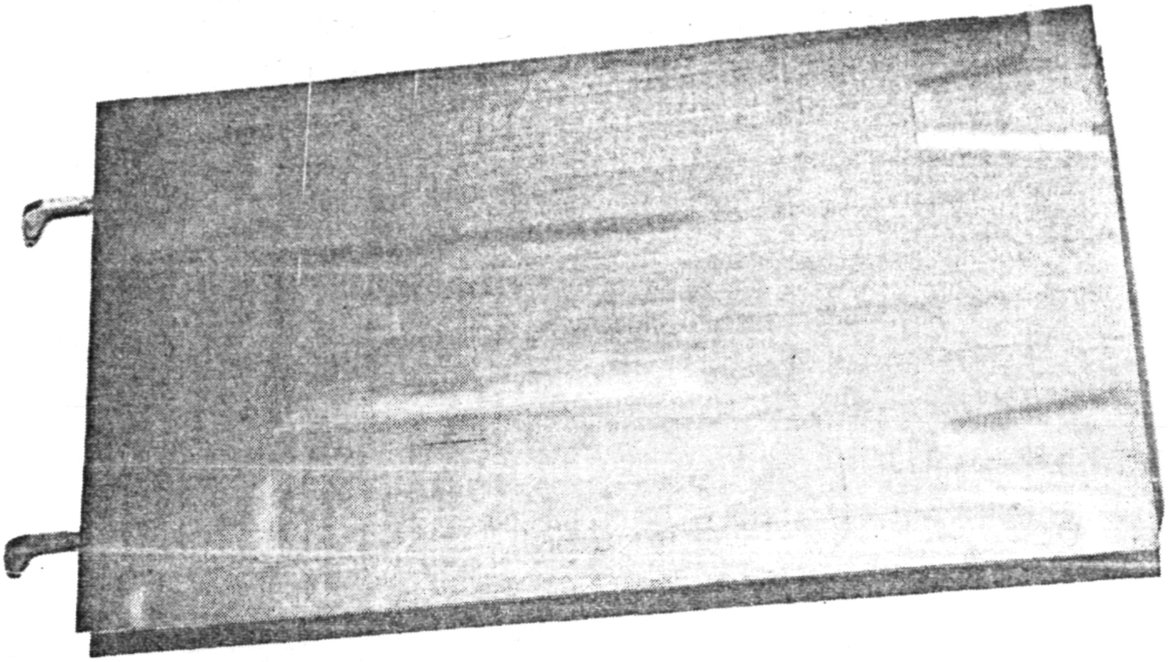

Figure 32. Graphite-faced sandwich door after removal from bonding jig

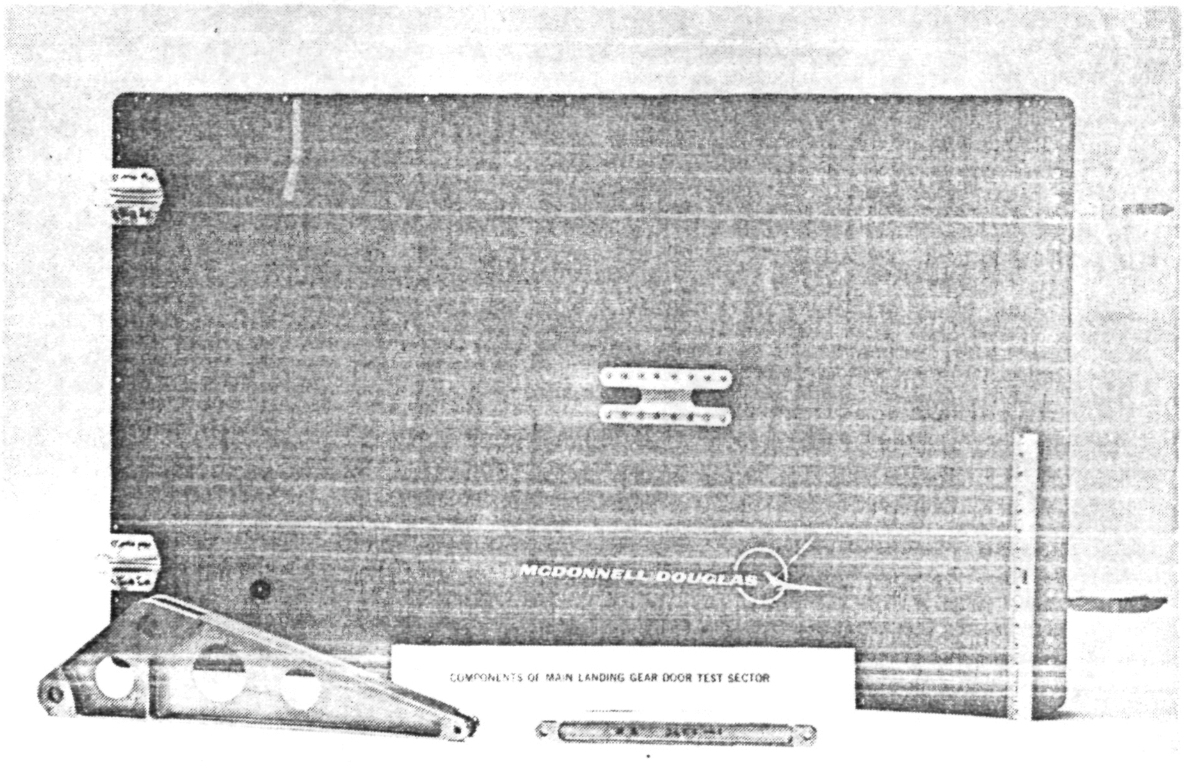

Figure 33. Components of main landing gear door test sector

TABLE 6

MID-SECTOR WEIGHTS

Item	Weight			
	kg		(lb)	
	Actual	Estimated	Actual	Estimated
1. Honeycomb core sections	3.722	3.87	8.21	8.52
2. Two-19 channels	0.176	0.19	0.387	0.42
3. Two-21 channels	0.463	0.50	1.019	1.10
4. Two-23 channels	0.039	0.05	0.086	0.10
5. Two-25 channels	0.050	0.05	0.110	0.10
6. Two IT42862 inserts	0.396	0.37	0.872	0.82
7. Two IT42861 inserts	1.701	1.65	3.750	3.63
8. One IT42859 insert	0.810	0.72	1.785	1.58
9. FM 40 foaming adhesive	1.090	2.02	2.400	4.47
Total weight, core subassembly	8.450	9.42	18.60	20.74
10. Two-3 skins	4.746	4.09	10.45	9.01
11. Metlbond 329 adhesive	1.273	1.08	2.80	2.38
Total weight, door with skins bonded	14.469	14.59	31.9	32.13
12. One IT42860 exterior fitting	0.236	0.23	0.520	0.52
13. Two IT42862-5 exterior fittings	0.416	0.42	0.917	0.92
14. Twelve-27 clips	0.082	0.07	0.180	0.15
15. Four-29 clips	0.020	0.02	0.044	0.05
16. Fasteners	0.091	0.07	0.200	0.15
Total weight, door with fittings	15.314	15.40	33.76	33.92

STRUCTURAL TESTING

This section summarizes work performed during phase III of the program, which was conducted in two stages of investigation. The first stage, which was partially concurrent with phase II, was primarily concerned with the fabrication of the test fixture. The second stage was devoted to various phases of testing, including test setup, instrumentation hookup and checkout, structural tests, and data acquisition. More detailed descriptions of phase III work are presented in reference 3.

The purposes of the structural tests were (1) to demonstrate and verify the structural integrity of the door sector and associated components, and (2) to provide data for evaluating the design concept of the graphite/epoxy sandwich door.

Test Requirements

Environments. —Testing was performed with the door sector in the following temperature environments:

1. Test no. 1: ambient.
2. Test no. 2: ambient.
3. Test no. 3: 394°K (250°F).

Tolerances. —Temperature tolerance was ±258°K (±5°F). Pressure tolerance was ±5 percent.

Inspection. —All strain gage and thermocouple installations were inspected by MDAC. The test setup and testing conditions required no inspection other than that given by the test conductor.

Loads. —The structural requirements for testing were as follows:

1. Test no. 1—An ultimate uniform pressure of 59.2 kN/m^2 (8.6 psi) acting on the door in the closed position at room temperature. This is the ultimate interference pressure on the MLDGA during Shuttle ascent.
2. Test no. 2—A cyclic uniform pressure of 1.97 kN/m^2 (0.285 psi) applied 400 times and one cycle of 0.400 psi applied on the down-position opened door at room temperature. This cyclic loading results from ground-effect aerodynamic loads on the doors at touchdown.
3. Test no. 3—An ultimate point loading of 35, 100 N (7, 880 lb) applied at the door center fitting normal to the door surface at a temperature of 394°K (250°F). This load occurs in the event that the door latches jam just prior to opening.

Test Fixture

Test fixture design. —The test fixture and setup were designed with the concept of utilizing the fixture for the three test conditions.

For test no. 1, a self-contained setup was used. A butyl rubber bladder whose dimensions corresponded to the test specimen was fabricated to apply a uniform pressure over the door surface. A backup pressure plate with side restraints was fabricated to react the bladder pressures. Structural steel angles bolted to the pressure plate, encompassing the test specimen on the short sides, formed the self-contained fixture setup (see schematic in fig. 34). For tests 2 and 3, steel erector-set beams, aluminum-and-steel fittings, a boron/epoxy hybrid column, and an all-titanium pivot beam were used to

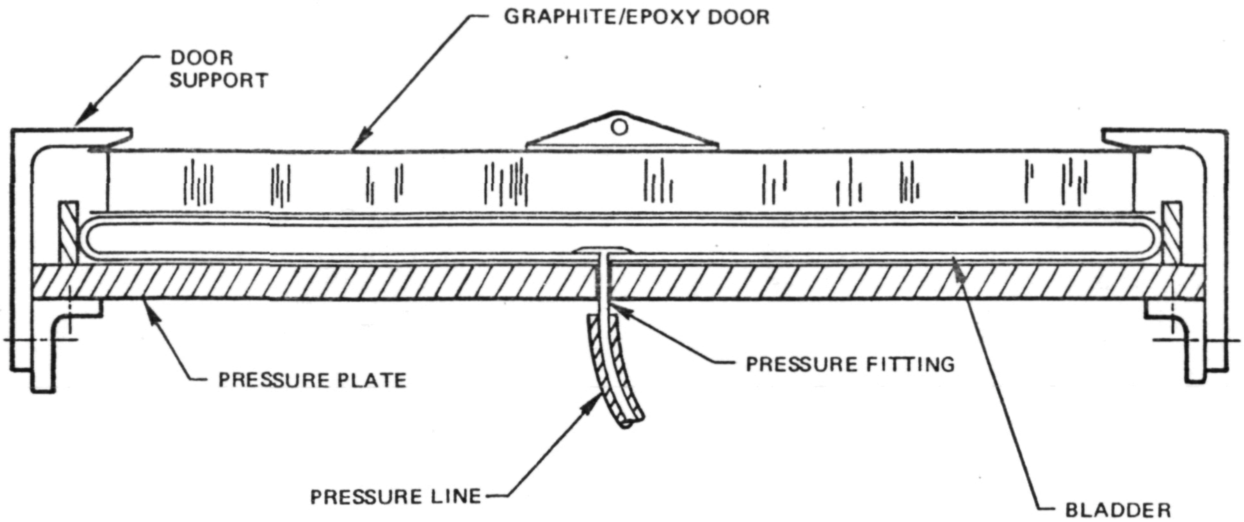

Figure 34. Schematic of uniform pressure load application

react the test loads. Three reaction points, two for the steel hinges and one at the center fitting, were required for test no. 2 (see schematic in fig. 35). Two additional points of support at the uplatches were used for test no. 3 (see schematic in fig. 36). The detailed drawing showing various hardware for the test setup is presented in figure 37.

Reflector. —A heat reflector was fabricated using an aluminum reflector with an array of 31 quartz lamps. For test no. 3, these lamps were located on the reflector to heat the specimen skin surface uniformly to 394°K (250°F) (see fig. 38). The fabricated reflector assembly is as shown in figure 39.

Test Equipment and Instrumentation

Static test equipment. —The test equipment used in testing the MLGDA door panel was as follows:

1. Pressure console.
2. DAS 200 data acquisition system.
3. Headsets.
4. 0.254-m (10-in.) jack.

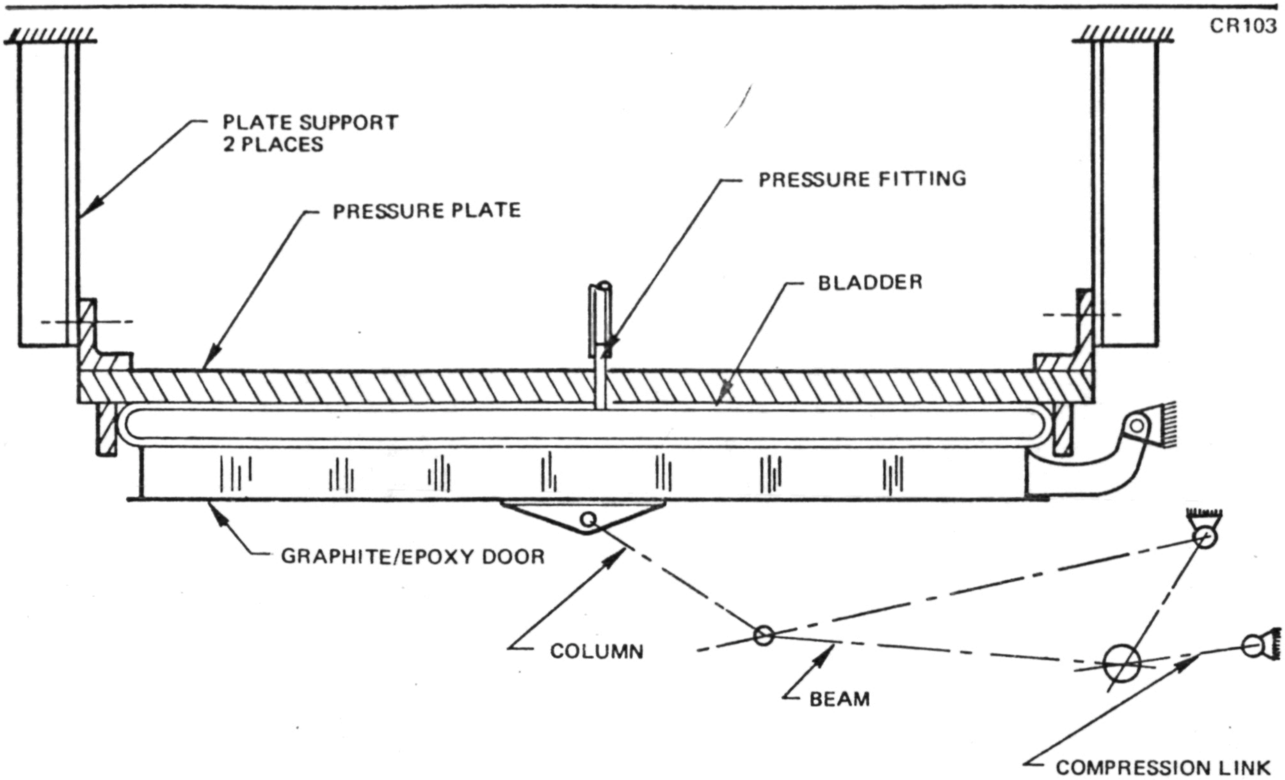

Figure 35. Schematic of cyclic test setup for a uniform load

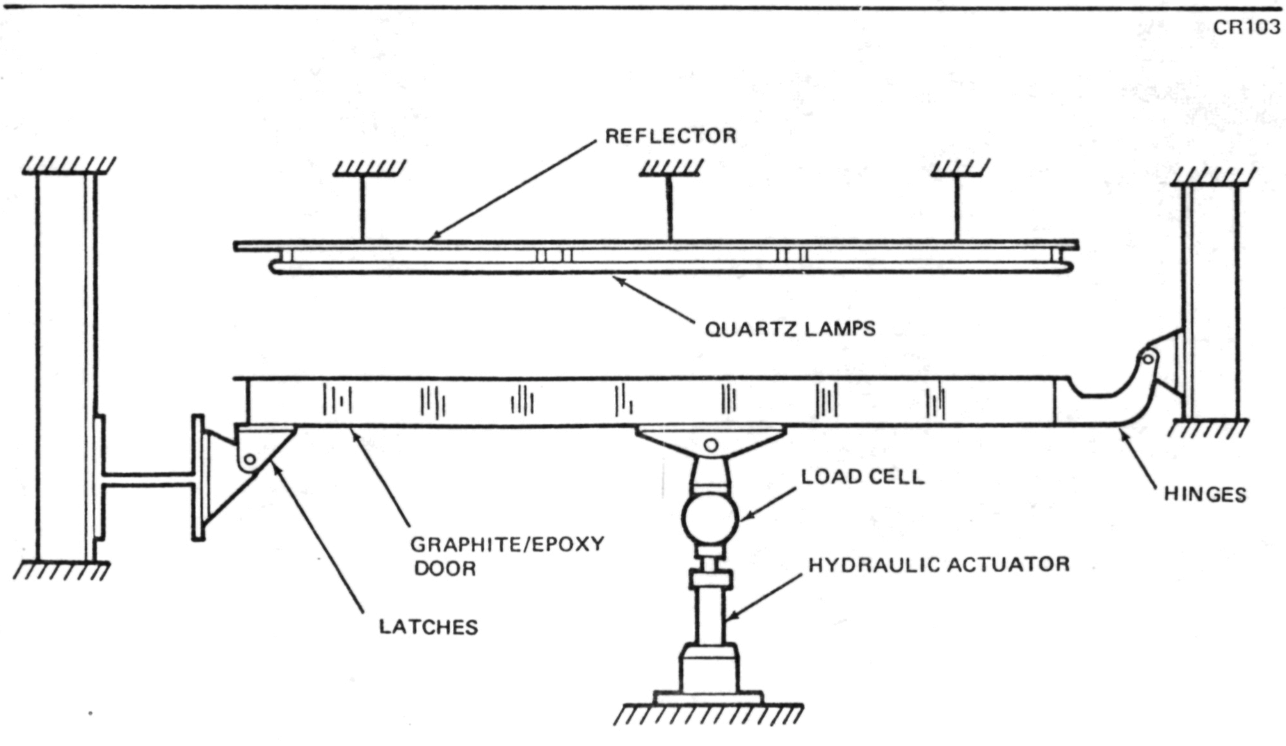

Figure 36. Schematic of concentrated load test at 394°K (250°F)

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Figure 37. Fixture and test setup for MLGDA test door (IT43194)

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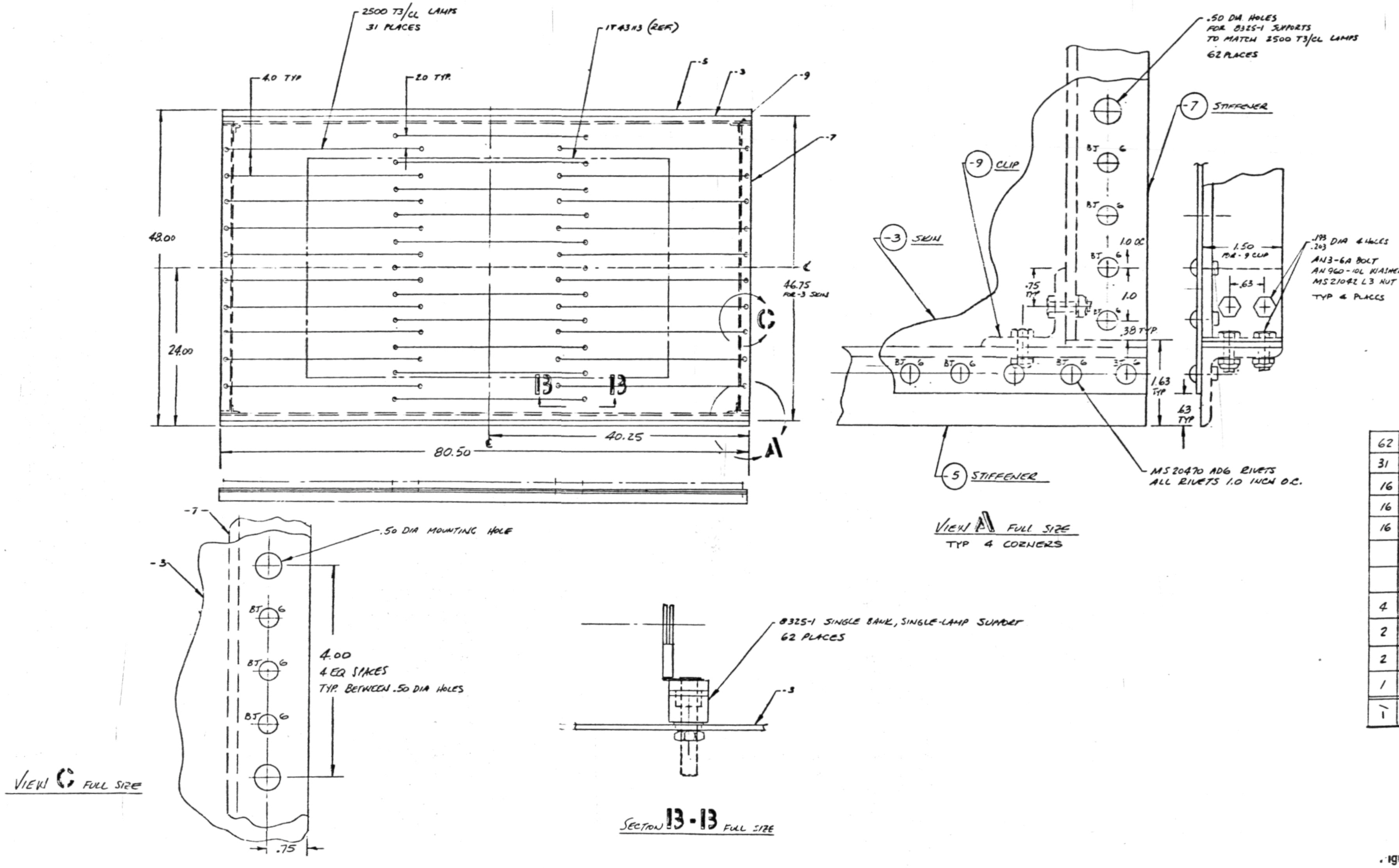

GENERAL NOTES: UNLESS NOTED.

1. INSTALL BOLTS PER IP30127
2. INSTALL RIVETS PER IP00127
3. EDGE DISTANCE FOR ALL ATTACHMENT IS 2D
4. INSTALL LAMPS PER GEN-MS-R-3581
5. MS20470 AD6 RIVETS INDICATED THUS BJ|6

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES ± —
3 PLACE DECIMALS ± .010
2 PLACE DECIMALS ± .030

SD 177232-05
SWO 66445
ASET 7120

62	8325-1	LAMP SUPPORT			
31	2500 T3/CL	LAMPS			
16	MS21042 L3	NUT			
16	AN960-10L	WASHER			
16	AN3-6A	BOLT			
4	-9	CLIP	MAKE FROM S-1046485-0116		COM'L.
2	-7	STIFFENER	MAKE FROM S-1046485-4500		COM'L
2	-5	STIFFENER	MAKE FROM S-1046485-8100		COM'L
1	-3	SKIN	.073 x 46.75 x 80.50	AL SHEET 6061-T6	COM'L
~~1~~	PART NUMBER	NAME DESCRIPTION	STOCK SIZE	MATERIAL DESCRIPTION	SPECIFICATION

Figure 3E. Reflector assembly for MLGDA test door (IT43196)

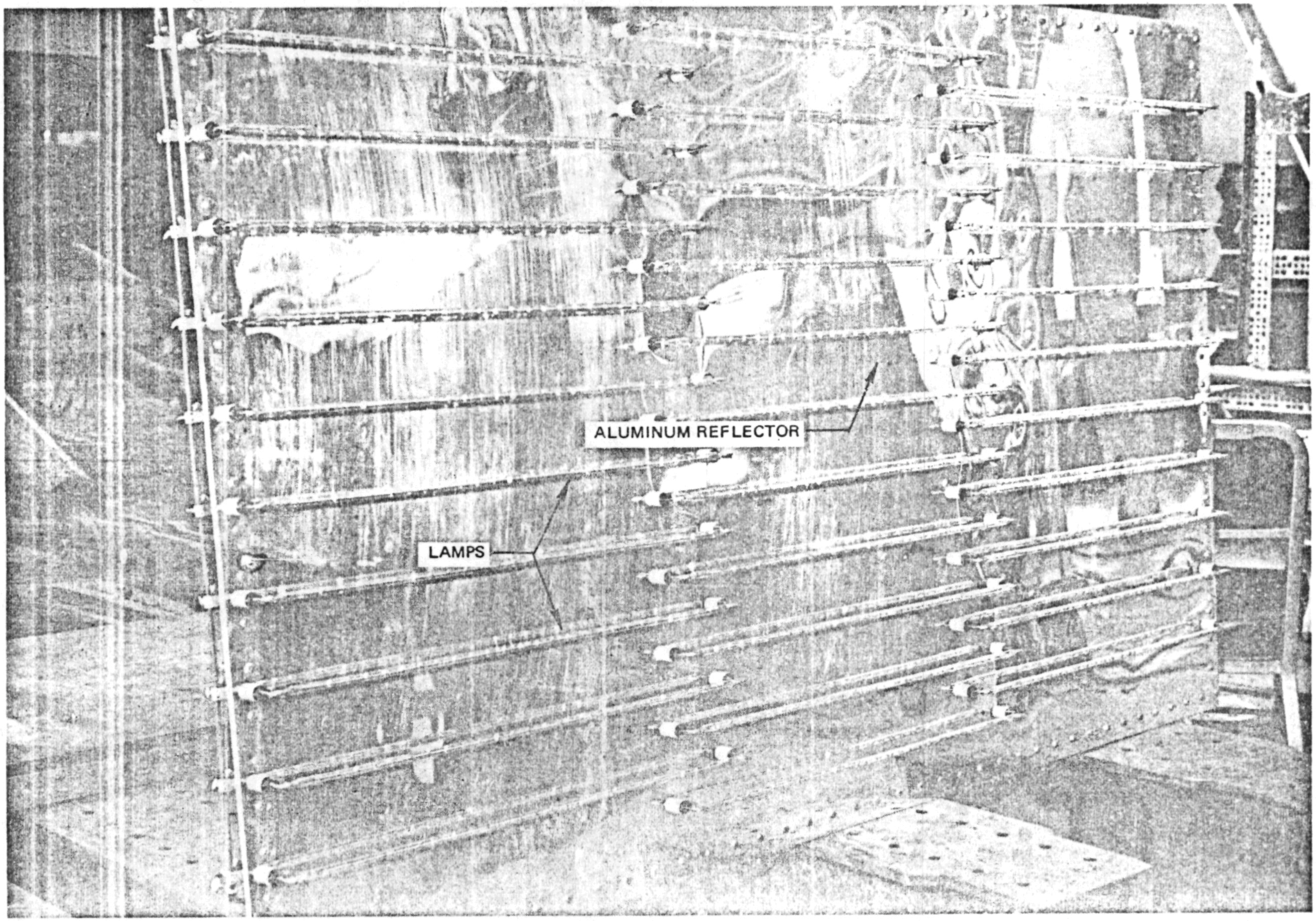

Figure 39. Heat reflector for test no. 3

5. Counter.

6. Omnigraph.

All equipment was within the valid certification period.

Instrumentation. —The test specimen was instrumented with 13 strain gages, 9 temperature sensors (figs. 40 and 41), 2 pressure transducers, and 2 deflection potentiometers. The DAS 200 data acquisition system was used to record the strain gage data.

It is noted that the same door sector was used in all three tests. It was important to monitor strain levels at all times during the first two tests to detect signs of premature failure. Instant flashback of strain data at the test site was therefore most helpful in determining whether the next higher load level should be attempted.

Test Setup and Test Procedure

Pretests. —Prior to each test condition, the system was preloaded to approximately 20 percent of limit test load to verify the loading system.

For test no. 3, in addition to the preload, heat of 339°K (150°F) maximum was applied to the door surface to check out the heating system.

Test no. 1 (uniform pressure load). —Following are the instructions used for conducting test no. 1:

> Install the door panel in the test setup fixture as shown on figure 42. Connect the pressure hose to the air pressure cell and check the system for leaks. Connect the strain gages and deflection potentiometer to the data acquisition system to record the incremental loading. Record calibrations and zero readings before starting the test loads. Pressurize the test panel in 6.89-kN/m^2 (1-psi) increments to 27.56 kN/m^2 (4 psi), then depressurize to zero. Proceed to pressures of 27.56, 34.45, 37.90, and 42.30 kN/m^2 (4, 5, 5.5, and 6.14 psi), and then to zero. Proceed to pressures of 42.30, 48.20, 51.60, 55.12, and 59.30 kN/m^2 (6.14, 7, 7.5, 8, and 8.6 psi), and then to zero (see table 7). Record data at each load increment on the DAS 200. When test is completed, proceed to test no. 2.

Test no. 2 (cyclic pressure loading). —Following are the instructions used for conducting test no. 2:

> Install the door panel in the test setup fixture as shown on figure 43. Connect the pressure hose to the air pressure cell and check the system for leaks. Connect the strain gages and deflection potentiometer to the data acquisition system. Record calibrations and zero readings before starting the test cyclic loads. Pressurize the panel to 1.97 kN/m^2 (0.285 psi), then depressurize to zero, then to 1.97 kN/m^2

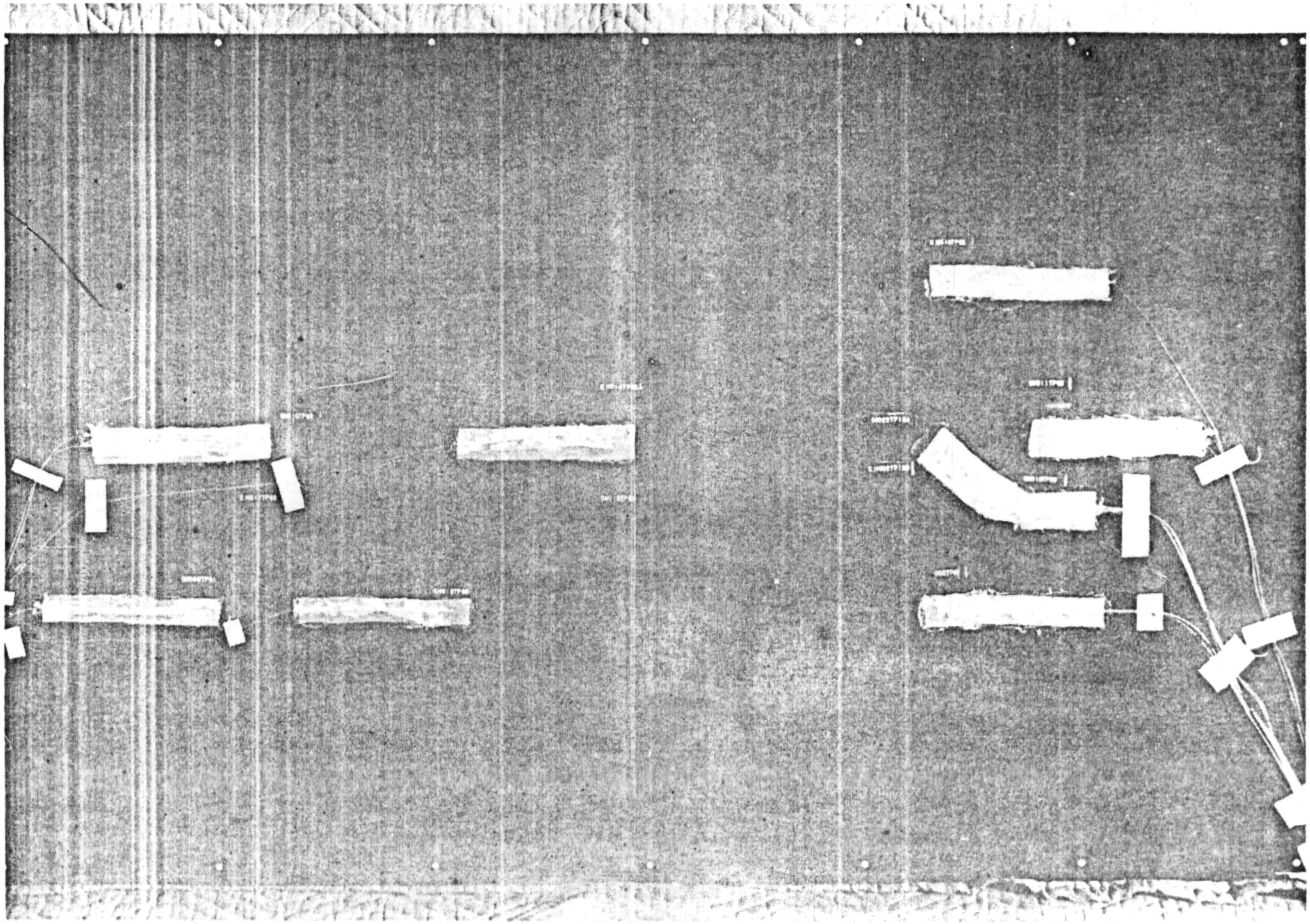

Figure 40. MLGDA test specimen – outside surface

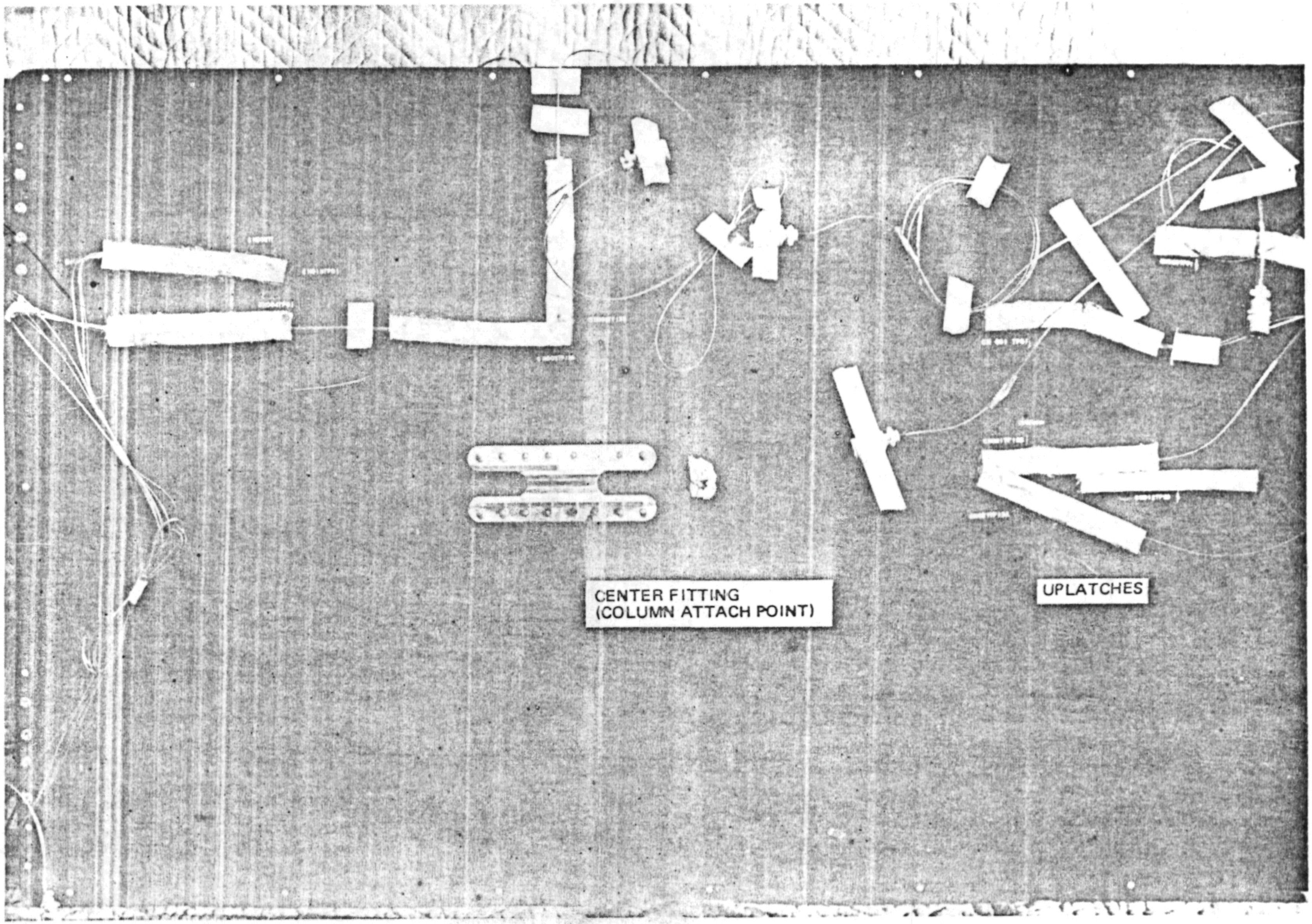

Figure 41. MLGDA door specimen – inside surface

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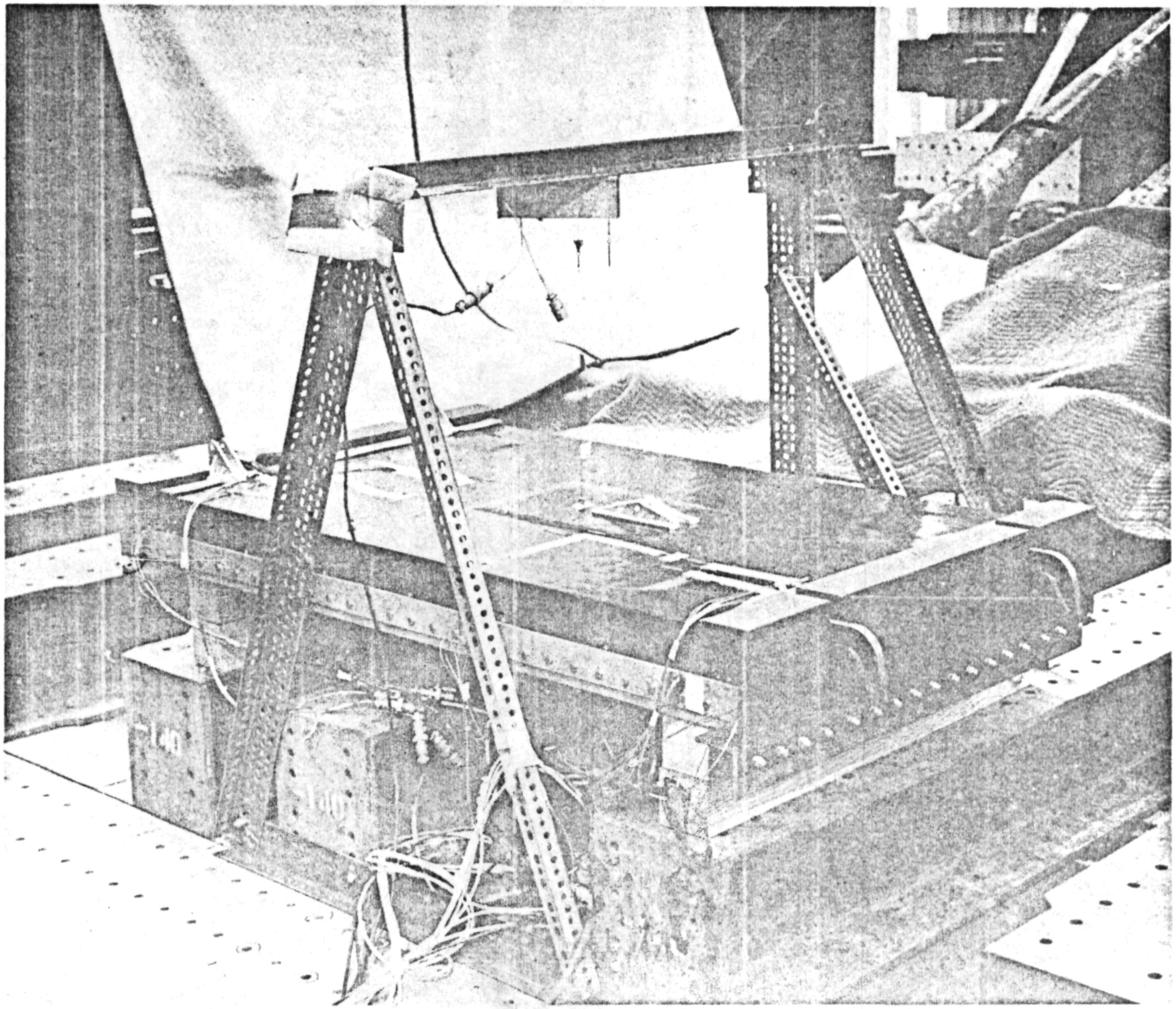

Figure 42. Setup for MLGDA pressure test no. 1

TABLE 7

TESTING SEQUENCE FOR GRAPHITE/EPOXY SANDWICH DOOR PANEL

Step	Procedure, test no. 1 (uniform loading), design limit load = 42.3 kN/m^2 (6.14 psi) design ultimate load = 59.3 kN/m^2 (8.60 psi)	Procedure, test no. 2 (cyclic loading), design limit load = 1.97 kN/m^2 (0.285 psi) design ultimate load = 2.76 kN/m^2 (0.400 psi)	Procedure, test no. 3, design limit load = 25.0 kN (5,630 lb) design ultimate load = 35.1 kN (7,880 lb)
1	Set up fixtures and test setup as shown on drawing 1T43194	Same as test no. 1	Same as test no. 1
2	Connect air pressure and instrumentation	Same as test no. 1	Same as test no. 1
3	Take cals	Take cals	Take cals
4	Read zero	Read zero	Read zero
5	Pressurize to 6.89 kN/m^2 (1 psi)	Pressurize to 1.97 kN/m^2 (0.285 psi)	Load to 10% 2.52 kN (565 lb)
6	Read	Read	Read
7	Pressurize to 13.78 kN/m^2 (2 psi)	Depressurize to 0 kN/m^2 (psi)	Load to 20% 5.04 kN (1,130 lb)
8	Read	Read	Read
9	Pressurize to 20.67 kN/m^2 (3 psi)	Pressurize to 1.97 kN/m^2 (0.285 psi) relieve pressure to 0 kN/m^2 (psi) then pressurize to 1.97 kN/m^2 (0.285 psi) then to zero, etc.	Load to 30% 7.56 kN (1,695 lb)
10	Read		Read
11	Pressurize to 27.6 kN/m^2 (4 psi)		Load to 40% 10.08 kN (2,260 lb)
12	Read		Read
13	Depressurize to 0 kN/m^2 (psi)		Load to 50% 12.60 kN (2,815 lb)
14	Read	At end of three cycles, read	Read
15	Pressurize to 27.6 kN/m^2 (4 psi)	Repeat step 9 to 100 cycles	Load to 60% 15.12 kN (3,380 lb)
16	Read	Read	Read
17	Pressurize to 34.5 kN/m^2 (5 psi)	Repeat step 9 to 200 cycles	Load to 70% 17.64 kN (3,940 lb)
18	Read	Read	Read
19	Pressurize to 37.9 kN/m^2 (5.5 psi)	Repeat step 9 to 300 cycles	Reduce load to zero
20	Read	Read	Read
21	Pressurize to 42.3 kN/m^2 (6.14 psi)	Repeat step 9 to 400 cycles	Load to 70% 17.64 kN (3,940 lb)
22	Read	Read	Read
23	Depressurize to 0 kN/m^2 (psi)	Pressurize to 2.76 kN/m^2 (0.400 psi)	Load to 80% 20.16 kN (4,505 lb)
24	Read	Read	Read
25	Pressurize to 42.3 kN/m^2 (6.14 psi)	Depressurize to 0 kN/m^2 (psi)	Load to 90% 22.50 kN (5,070 lb)
26	Read	Read	Read
27	Pressurize to 48.2 kN/m^2 (7 psi)	End of test	Load to 100% 25.0 kN (5,630 lb limit)
28	Read		Read
29	Pressurize to 51.6 kN/m^2 (7.5 psi)		Reduce load to zero
30	Read		Read
31	Pressurize to 55.1 kN/m^2 (8 psi)		Load to 100% 25.0 kN (5,630 lb)
32	Read		Read
33	Pressurize to 59.3 kN/m^2 (8.6 psi)		Load to 110% 27.5 kN (6,195 lb)
34	Read		Read
35	Depressurize to 0 kN/m^2 (psi)		Load to 120% 30.1 kN (6,760 lb)
36	Read		Read
37	End of test		Load to 130% 32.1 kN (7,235 lb)
38			Read
39			Load to 140% 35.1 kN (7,880 lb ultimate)
40			Read
41			Reduce load to zero
42			Read
43			Load to 140% 35.1 kN (7,880 lb)
44			Read
45			Load to 150% 37.6 kN (8,445 lb)
46			Read
47			Load to 160% 40.1 kN (9,005 lb)
48			Read
49			Load to 170% 42.6 kN (9,570 lb)
50			Read
51			Load to 180% 45.0 kN (10,130 lb)
52			Read
53			Load to 190% 47.5 kN (10,695 lb)
54			Read
55			Load to 200% 50.0 kN (11,260 lb)
56			Read
57			Load to 210% 52.6 kN (11,820 lb)
58			Read
59			Load to 220% 55.1 kN (12,385 lb)
60			Read
61			Load to 230% 57.6 kN (12,950 lb), failure

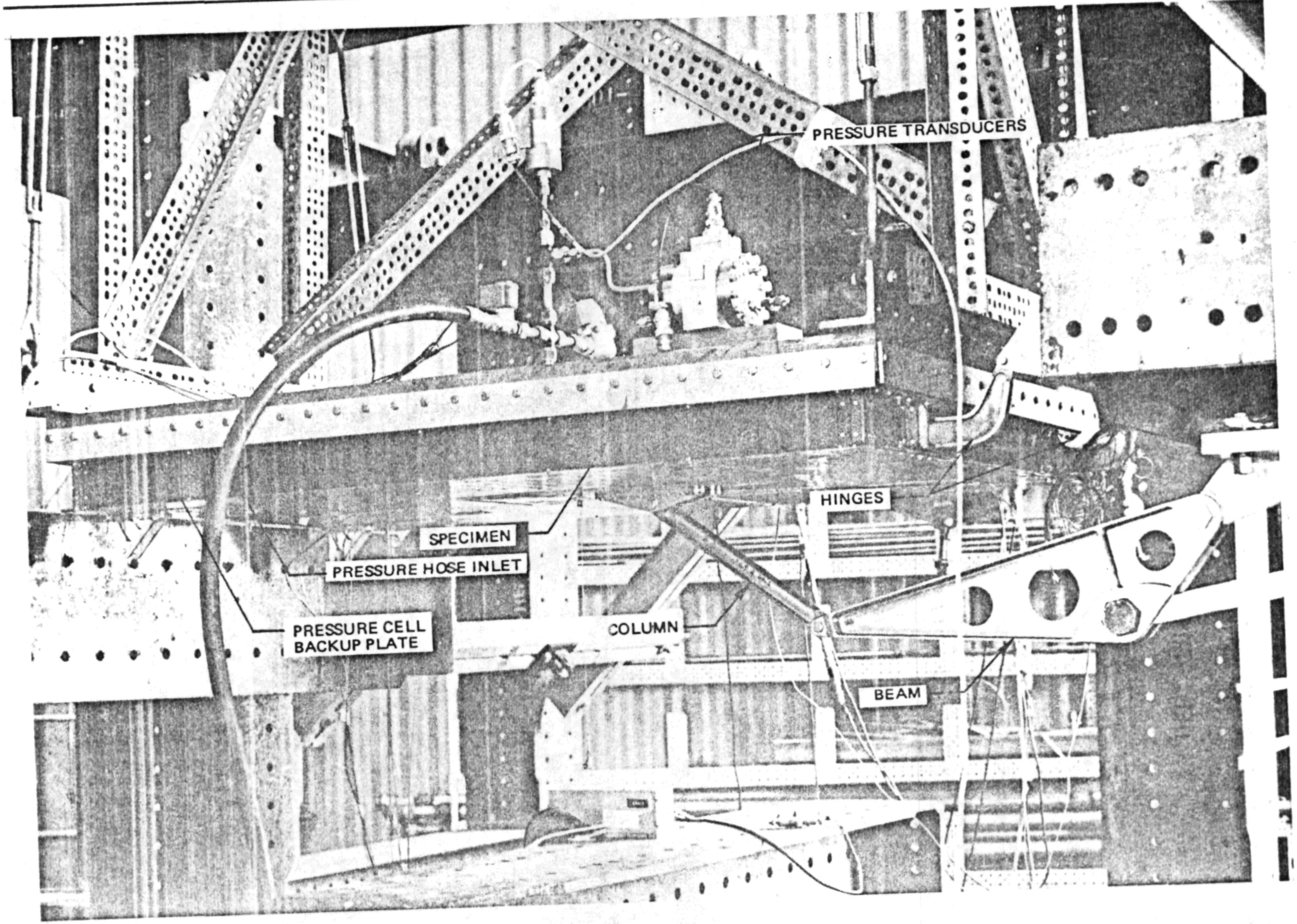

Figure 43. Setup for MLGDA pressure cyclic test no. 2

(0.285 psi) to zero, etc. Record 1.97- and zero-kN/m^2 (0.285- and zero-psi) readings for the 100th, 200th, 300th, and 400th cycles. Pressurize to 2.76 kN/m^2 (0.400 psi), then to zero for one cycle, and record. When test is completed, proceed to test no. 3.

Test no. 3 (concentrated load at 394°K [250°F]). —Following are the instructions used for conducting test no. 3:

Install the door panel in the test setup fixture as shown on figure 44. Connect the strain gages, thermocouples, load cell, and deflection potentiometers to the data acquisition system. Connect another output leg of the load cell to an omnigraph to monitor the concentrated test load. Connect the heat reflector to the power supply. Record calibrations and zero readings for no heat or load. Start the power supply to the heat reflector and stabilize the surface temperature of the test specimen at 394°K (250°F).

Record zero readings.

Load specimen in 10-percent increments to 70 percent of limit load and record data for each increment. Reduce load to zero and record data. Load specimen to 70, 80, 90, and 100 percent of limit load and record data for each increment. Reduce load to zero and record. Load specimen to 100, 110, 120, 130, and 140 (ultimate) percent of limit load and record data for each increment. Reduce load to zero and record data. Load specimen to 140 percent of limit load and then increase load in 10-percent increments until failure of test specimen. Record data for each increment of load.

Test is complete.

Test Results

Test no. 1 (uniform pressure test). —The test specimen withstood the ultimate uniform pressure test with no apparent distortion, damage, or failure. Strain gage readouts and pressure and deflection data are documented in detail in reference 3.

Test no. 2 (cyclic loading). —The test specimen withstood the cyclic loading with no apparent distortion, damage, or failure. Test data are documented in detail in reference 3. Free-end deflections with and without pressure load are shown in figures 45 and 46, respectively.

Test no. 3 (concentrated load at 394°K [250°F]). —The door sector was first tested to limit load (fig. 47), then to ultimate (140 percent of limit) load as shown in figure 48. The door withstood ultimate load with no visible signs of failure or damage. Load was applied in 10-percent increments following ultimate load application. Deflected shape of the door at 200 percent of limit load is indicated in figure 49. The test door failed at 230 percent of limit load (fig. 50). Failure occurred across the short side at approximately 0.534 to 0.609 m (21 to 24 in.) from the latch fitting side of the door. Figures 51 through 55 depict failure areas as viewed from various angles. Strain data, deflections, and temperatures are documented in detail in reference 3.

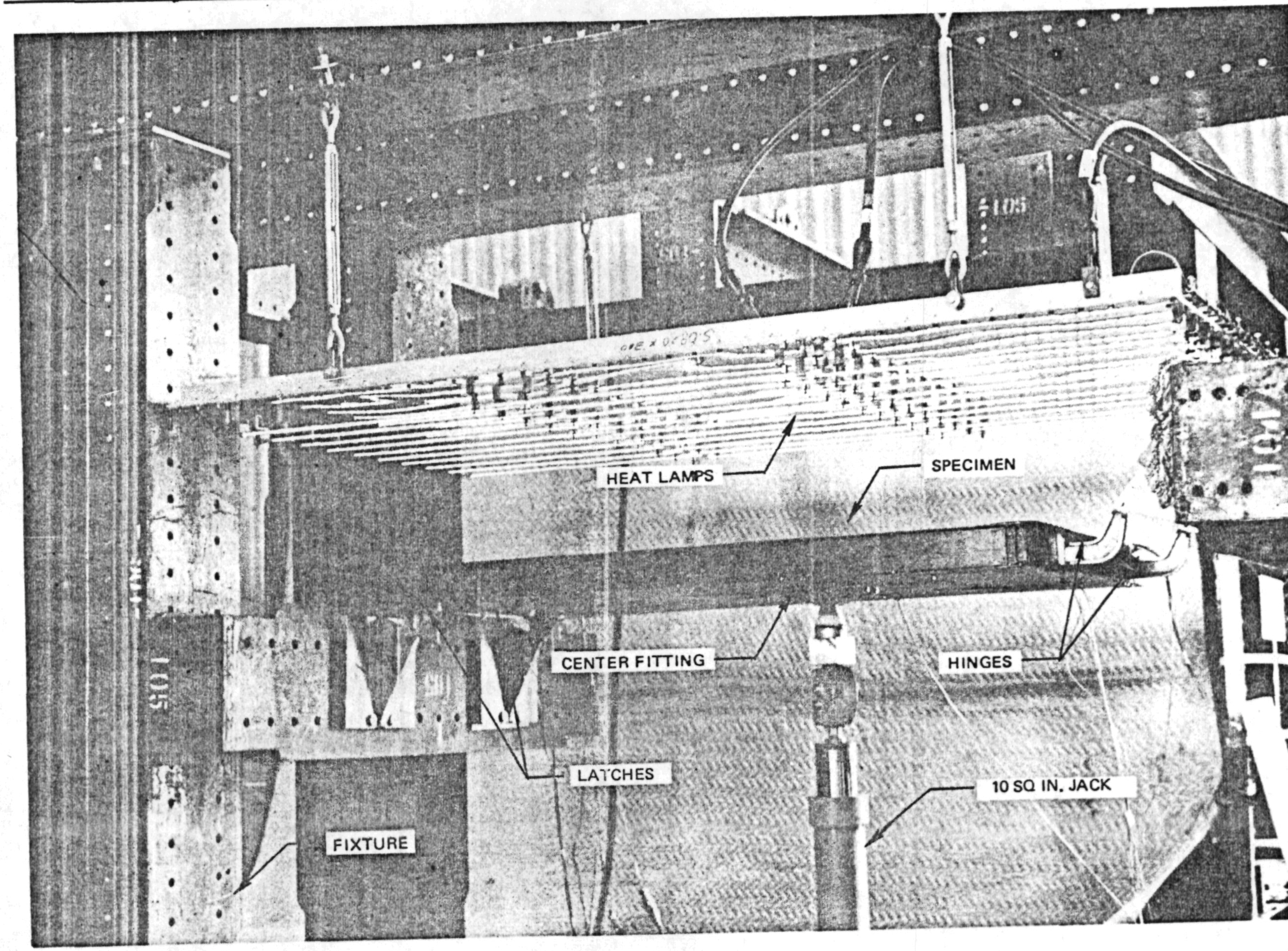

Figure 44. Setup for MLGDA concentrated load test no. 3

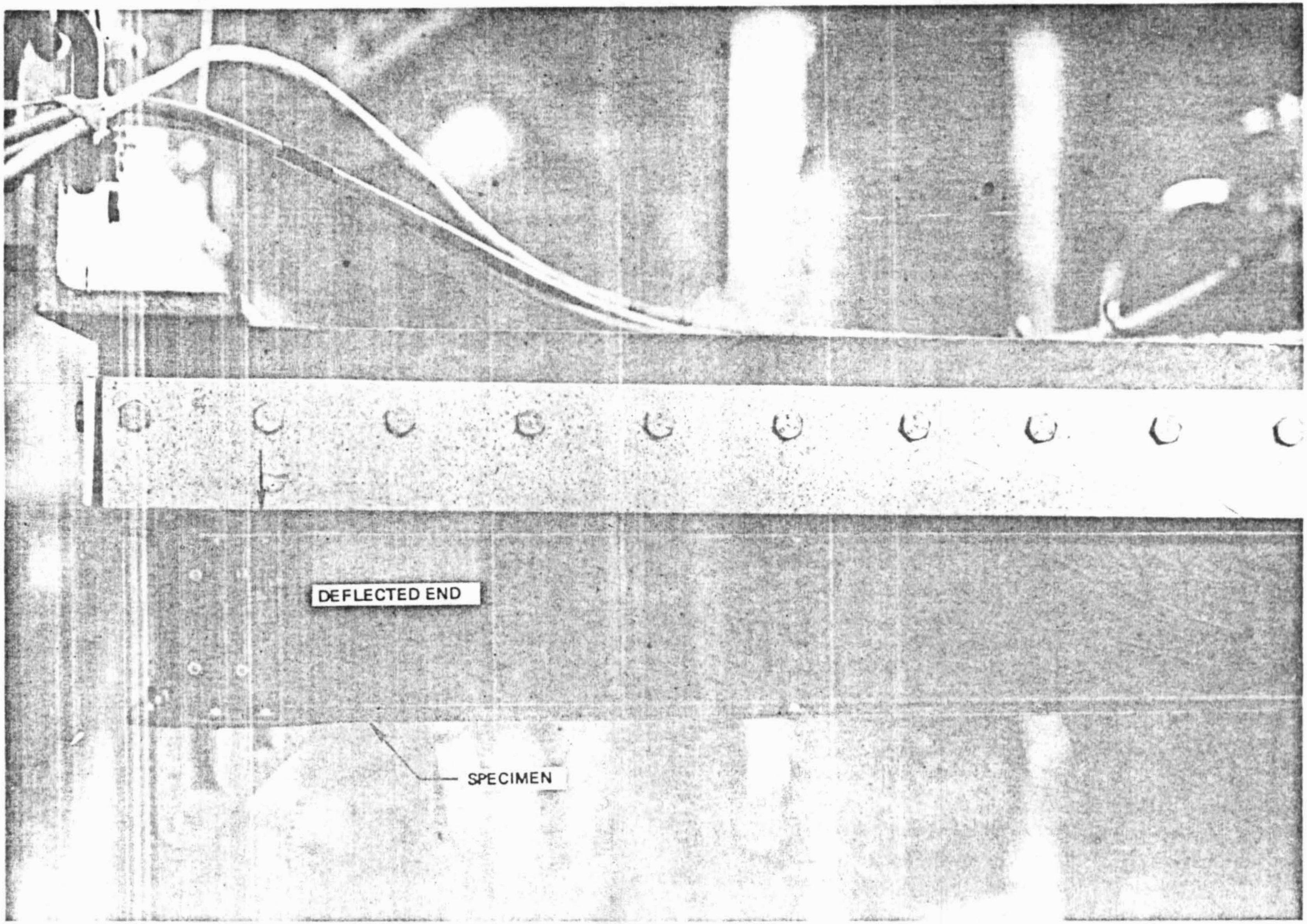

Figure 45. View showing deflected end – loaded test no. 3

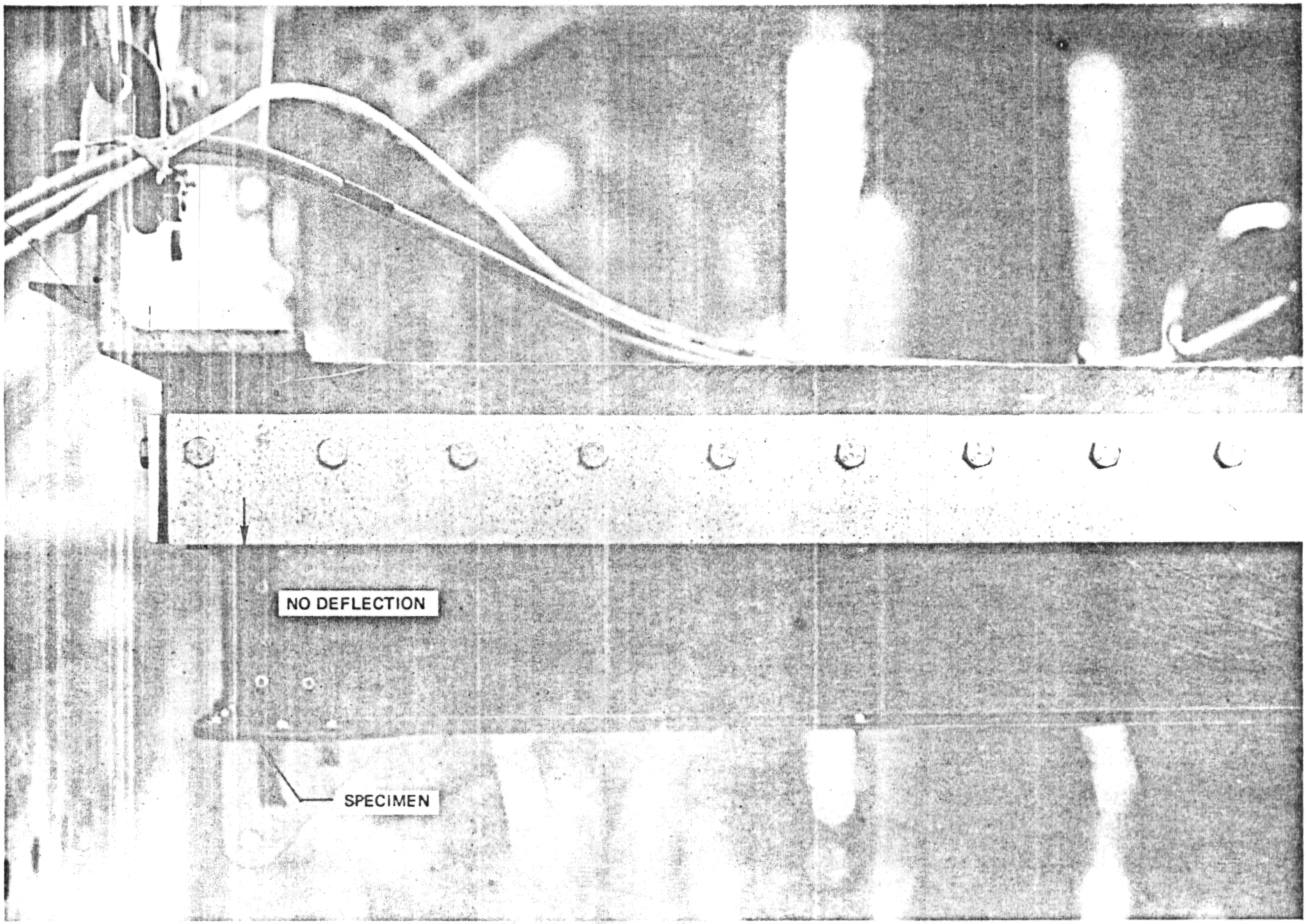

Figure 46. View showing deflection end – no-load test no. 2

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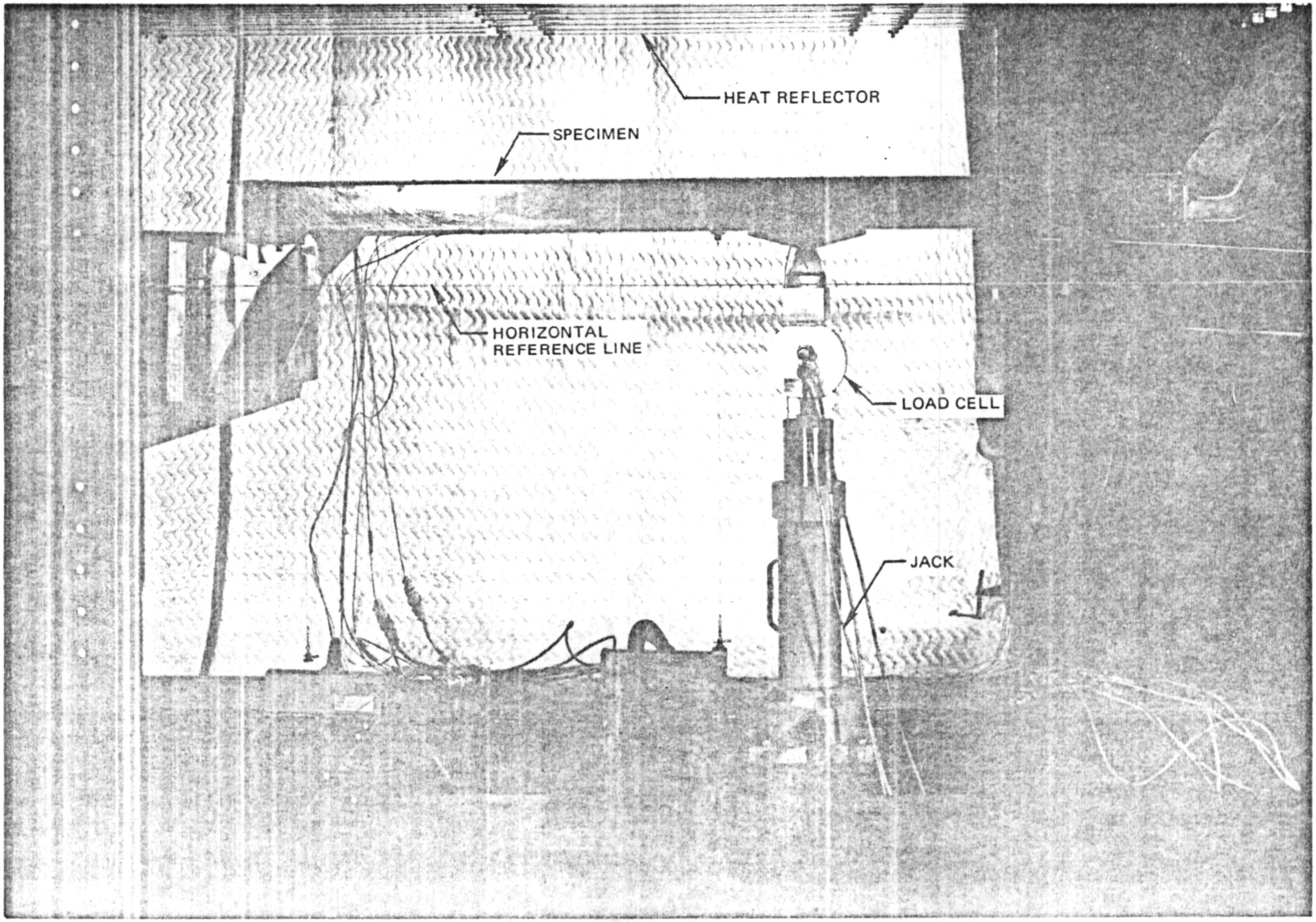

Figure 47. MLGDA 100-percent limit load test no. 3

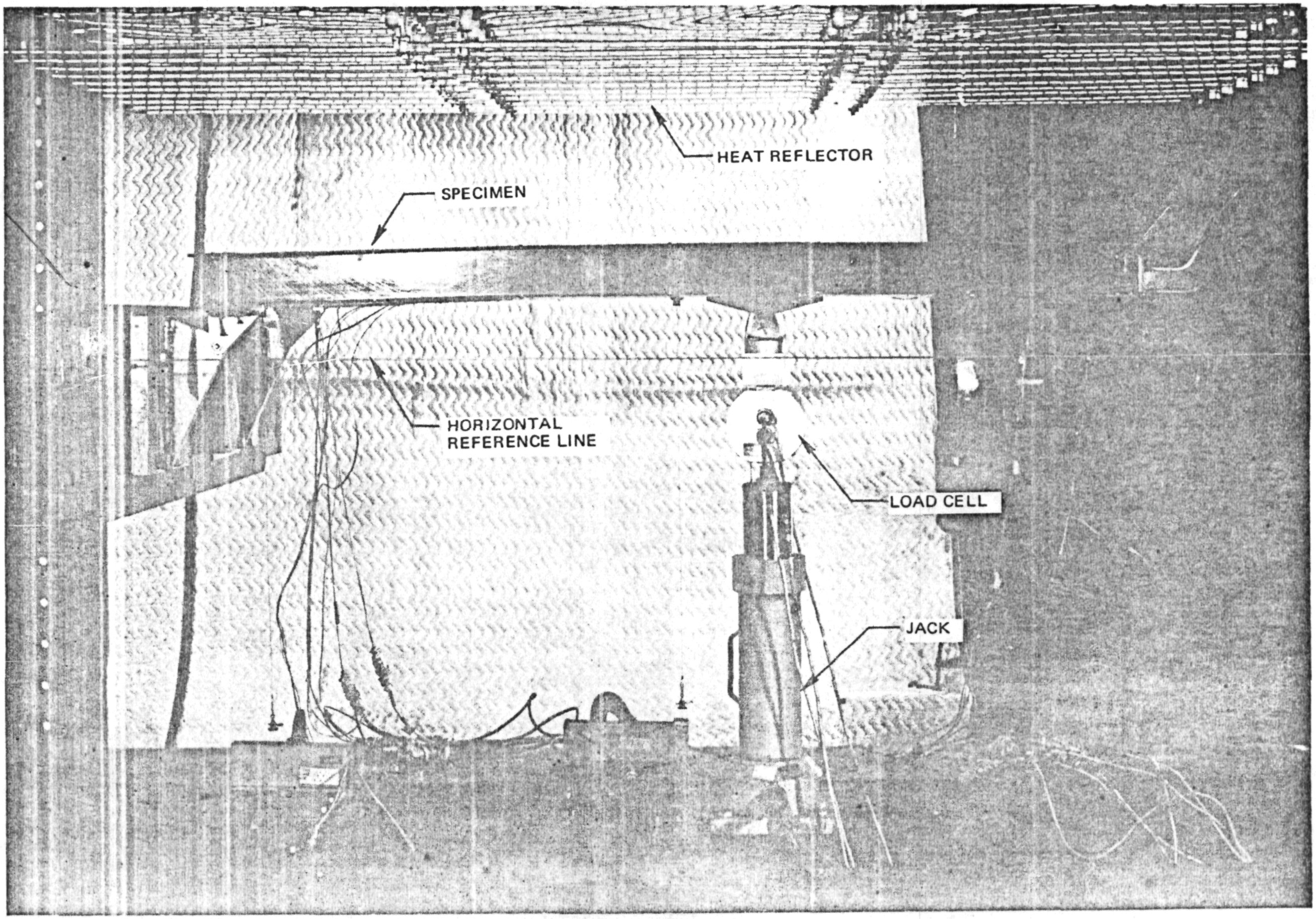

Figure 48. MLGDA 140-percent limit load test no. 3

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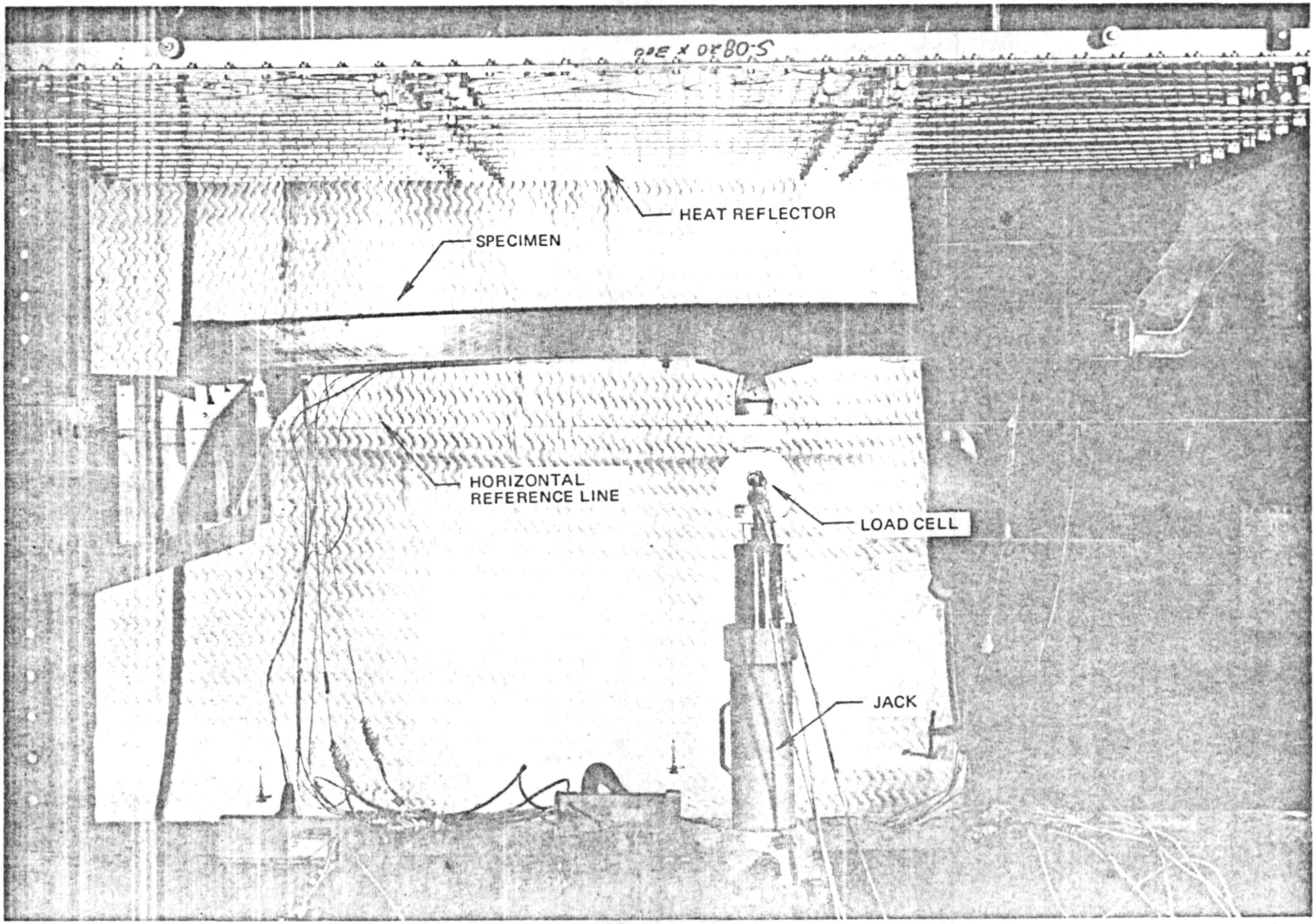

Figure 49. MLGDA 200-percent limit load test no. 3

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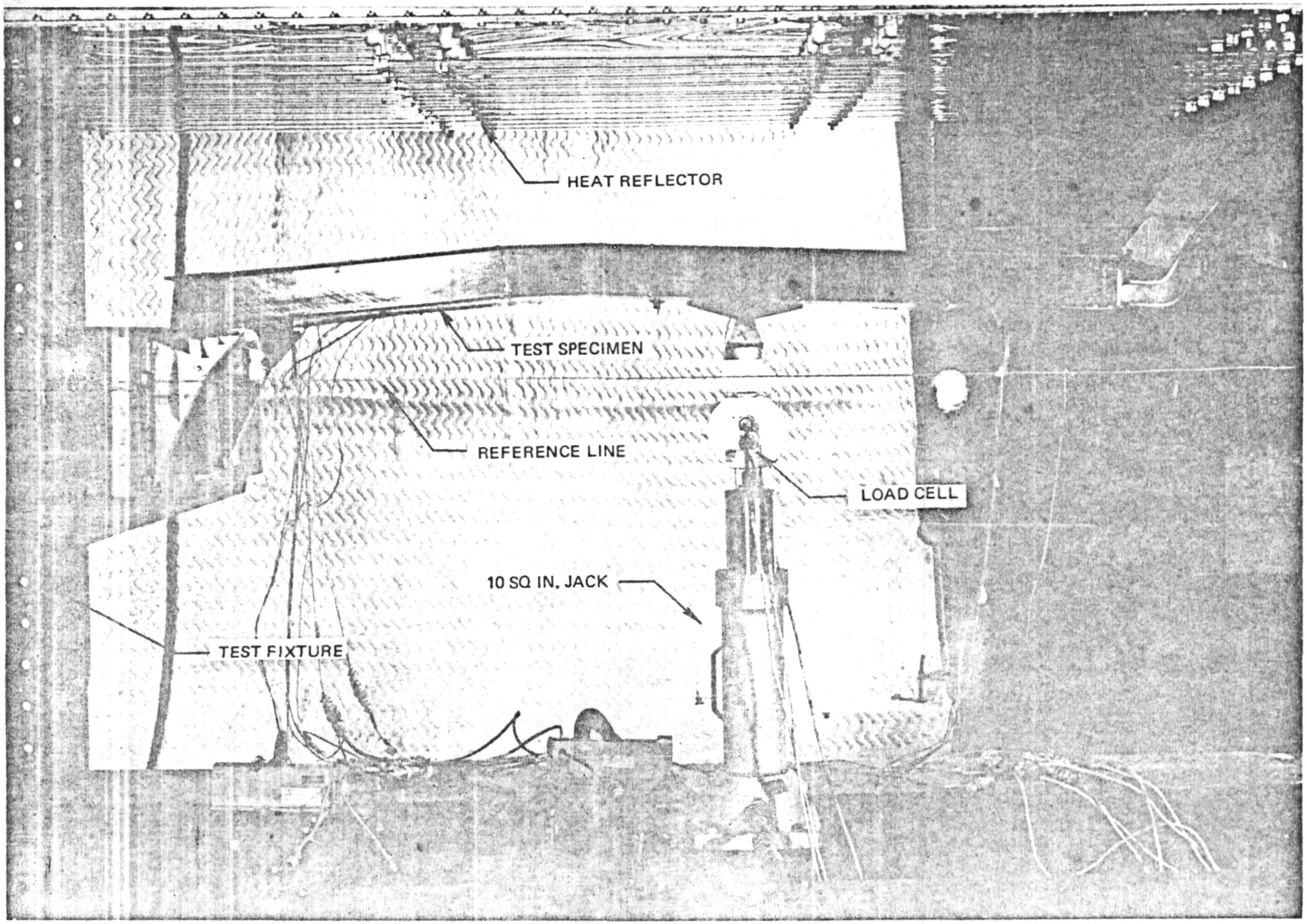

Figure 50. MLGDA 230-percent limit load (failure) test no. 3

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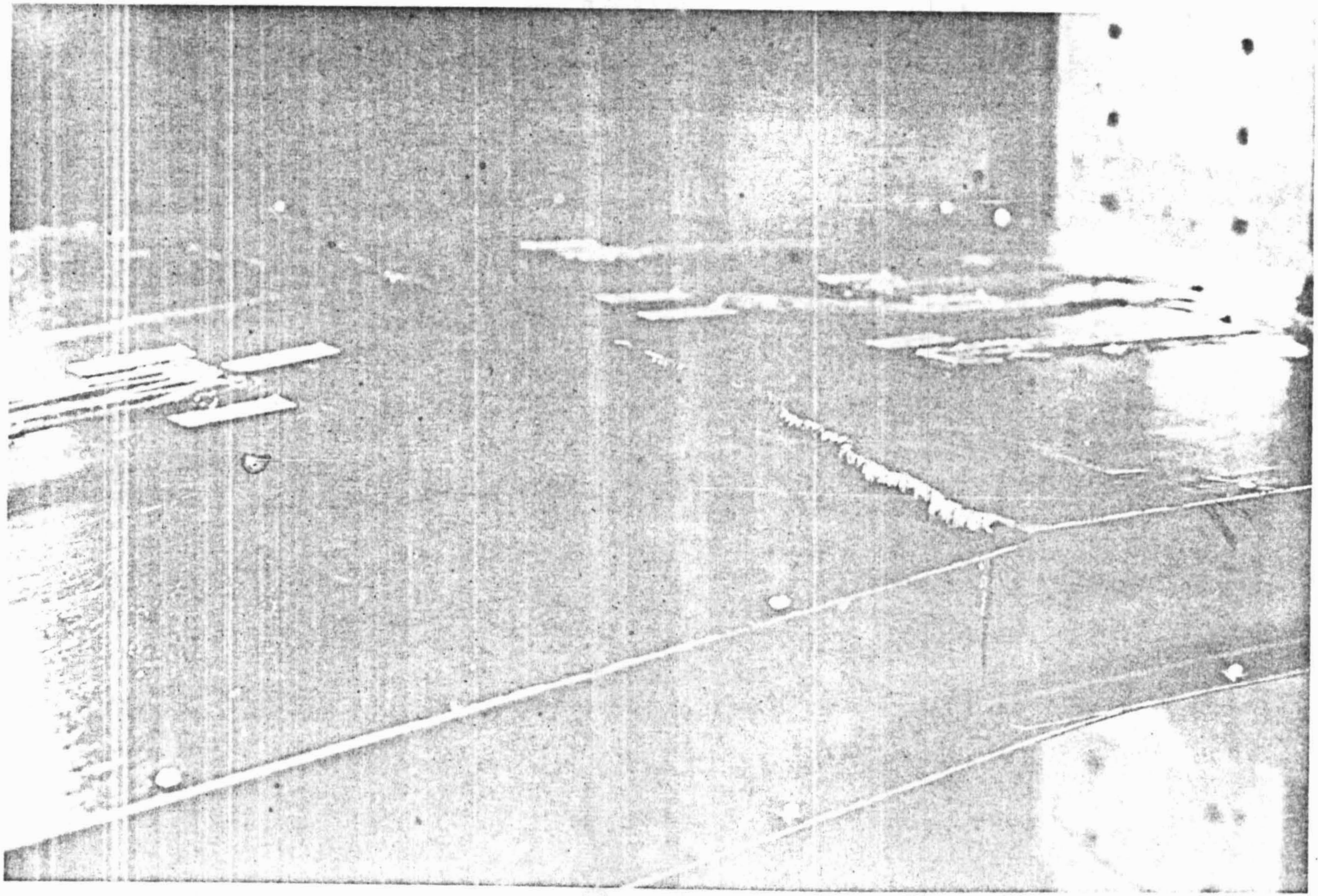

Figure 51. View showing skin tension failure from far side

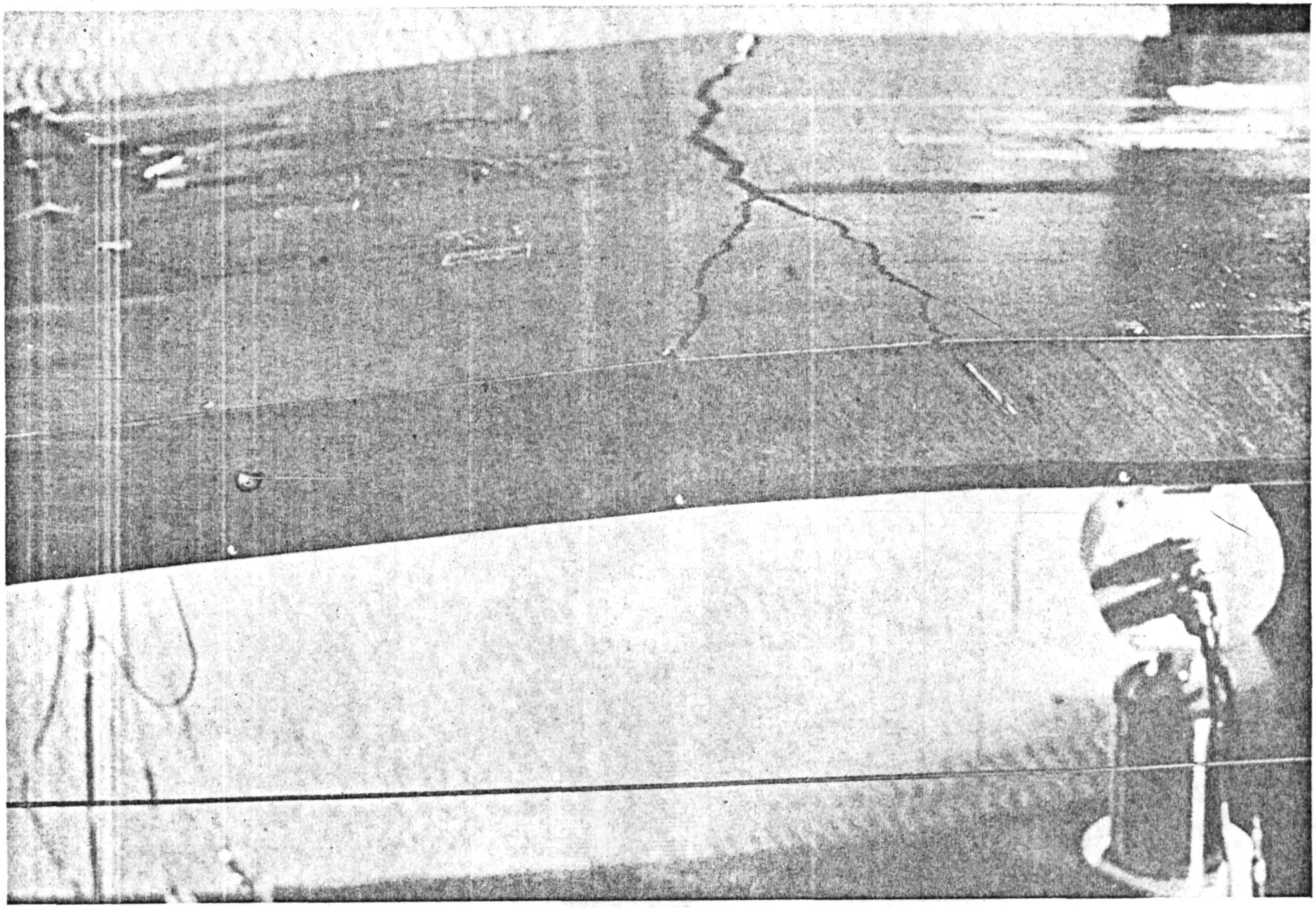

Figure 52. View showing skin tension failure from near side

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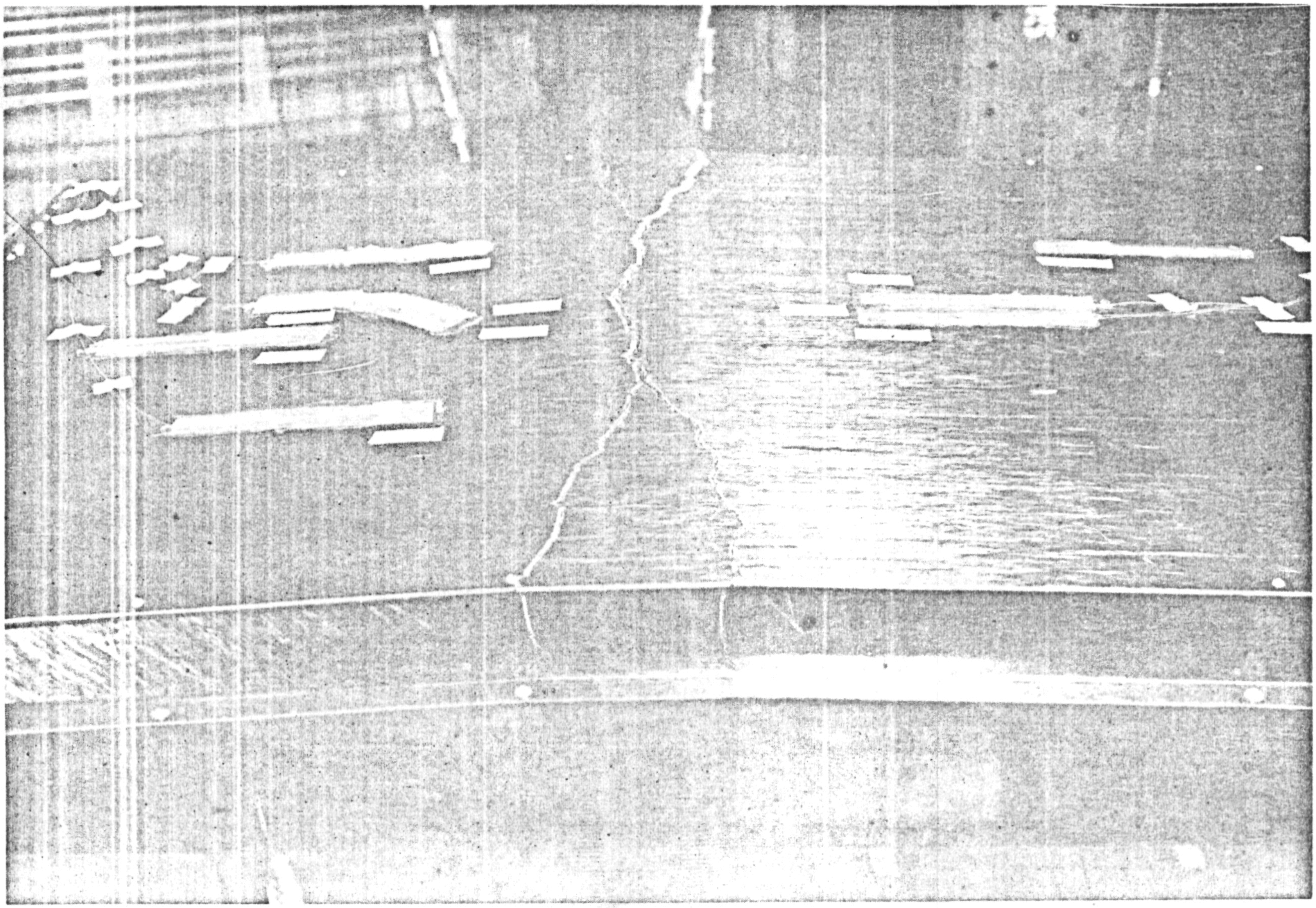

Figure 53. View showing skin failure from top side

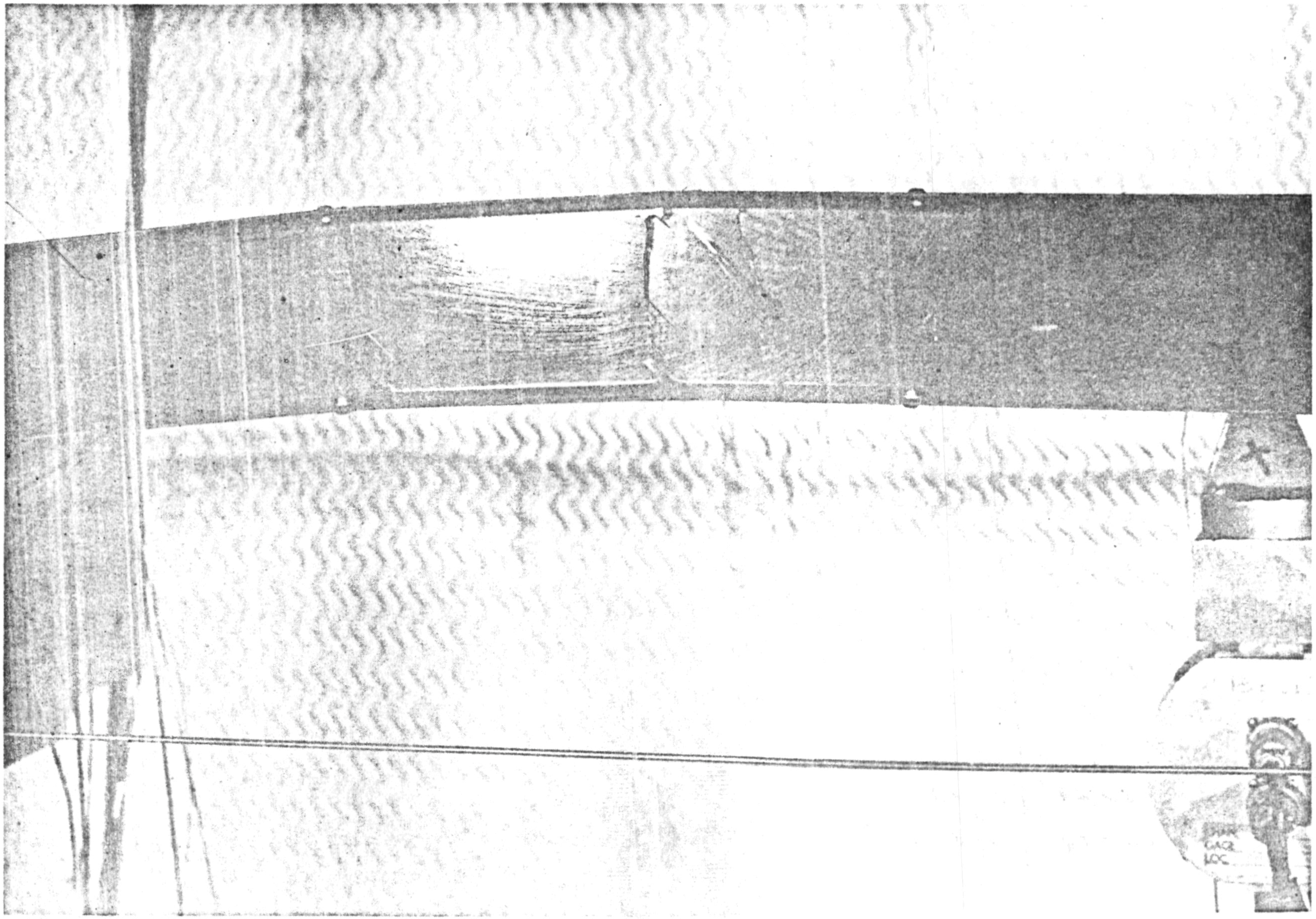

Figure 54. View of edge channel failure – near side

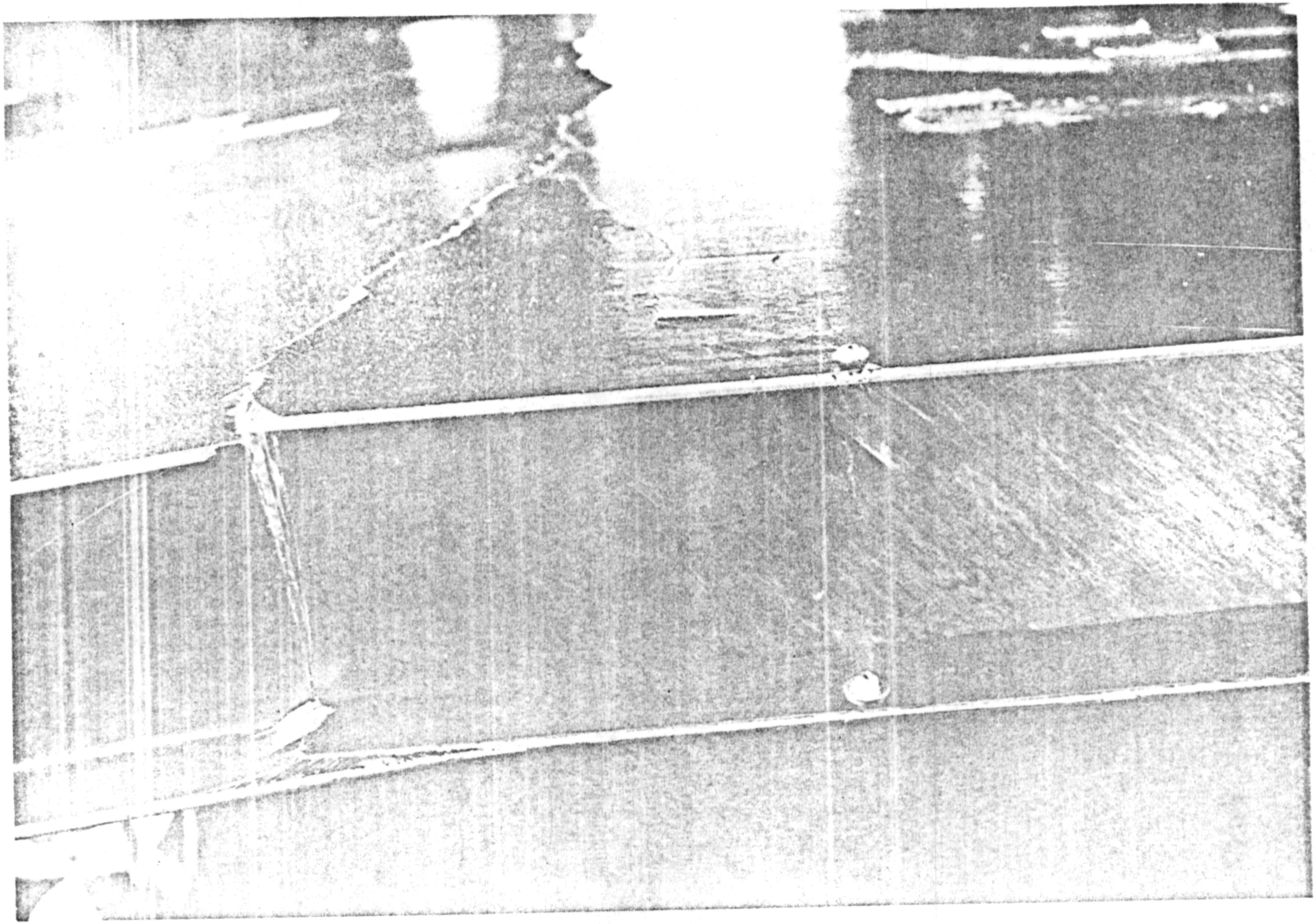

Figure 55. View of skin and edge channel failure — far side

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POSTTEST REVIEW

Pressure Tests

In the uniform pressure test at room temperature, the Gr/Ep door sector under the ultimate load of 59.3 kN/m^2 (8.6 psi) was observed to assume an extremely smooth, deflected shape. This observation, plus the fact that no unusual stress distribution in the door skin was noted in the test data, suggested that the stiffness mismatch between the metal inserts and the aluminum honeycomb was effectively reduced. Hence, the designs of the inserts and the utilization of doublers at the insert locations are verified.

The cyclic pressure test demonstrated the adequacy of the Metlbond 329 film adhesive under cyclic loading. At the end of 400 pressure cycles, no debonding of the Gr/Ep skins was detected.

As shown by the strain gage data, the permanent deformation in the door skin was found to be practically zero after each pressure test. Thus, it can be safely assumed that when the door sector underwent the concentrated load test at 394°K (250°F) (test no. 3), it carried no adverse residual effects from the pressure testing.

The connecting column and the pivot beam, which were tested with the door sector under design condition D cyclic pressure loads, showed no abnormalities. This was to be expected, since the two components were designed for higher loadings for other design conditions.

Concentrated Load Test

The last test pertained to a concentrated load applied at the column fitting of the door sector. The outside surface (far side from the column fitting) of the door was programmed to be heated to a temperature of 394°K (250°F) by an array of quartz lamps. The actual temperature distribution throughout the entire outside surface was found to range between 393 and 394°K (247 and 250°F) after the 100-percent limit load was reached. The inside temperature was monitored to be between 371 and 372°K (207 and 209°F). Thus, the temperature dropped approximately 22°K (40°F) across the thickness of the door sector. The door sector, being pinned at the hinges and the latches, was found to undergo a thermal compressive strain of approximately -1,200 μcm/cm (μin./in.) prior to the load application, after allowance was made for apparent strain. This thermal strain reduced the tensile strain and increased the compressive strain during bending of the door from the concentrated load.

The door sector successfully completed the design limit and design ultimate load tests. The central deflection of the door at design ultimate load of 35,100 N (7,880 lb) was 0.018 m (0.71 in.). The load was then decreased to zero, and a deflection of 0.00002 m (0.008 in.) was read. Hence, the door sector sustained practically no permanent deformation under the ultimate load.

The concentrated load was then increased beyond the ultimate value until failure occurred at 230 percent of limit load, or 57, 500 N (12, 950 lb). The skin on the outside surface (tension side) of the door and the honeycomb core were cracked open across the width of the door, as illustrated in figure 56.

A review of the strain data, as recorded by the strain gages located on the outside surface of the door near the failure region, revealed tensile strains of less than 2, 000 μcm/cm (μin. /in.), or 0. 2 percent strain. This value is much below the 0. 7 to 0. 9-percent strain to failure of the Narmco 5206-II six-ply laminates found in earlier phase I coupon testing. Thus, it may be assumed that the skin failure was not due to excessive tensile strain from bending.

A preliminary check was made on the shearing of the core across the width of the test door sector. Based on the 57. 6 kN (12, 950-lb) failure load, the core shear stress was found to be less than half the core shear allowable. Therefore, transverse shear did not appear to be the cause of failure.

It was believed that the failure was due to the local effects of the X-shaped core insert. Under the action of the concentrated load, the insert was being pushed against the shear restraint offered by the surrounding honeycomb core. The four extremities of the X-insert (fig. 56) were, in essence, "poking" at the Gr/Ep skin, creating a hardpoint situation. Since the skin was reinforced by doublers that extended over the X-insert, the poking phenomenon manifested itself at the nearest weaker section. In this case,

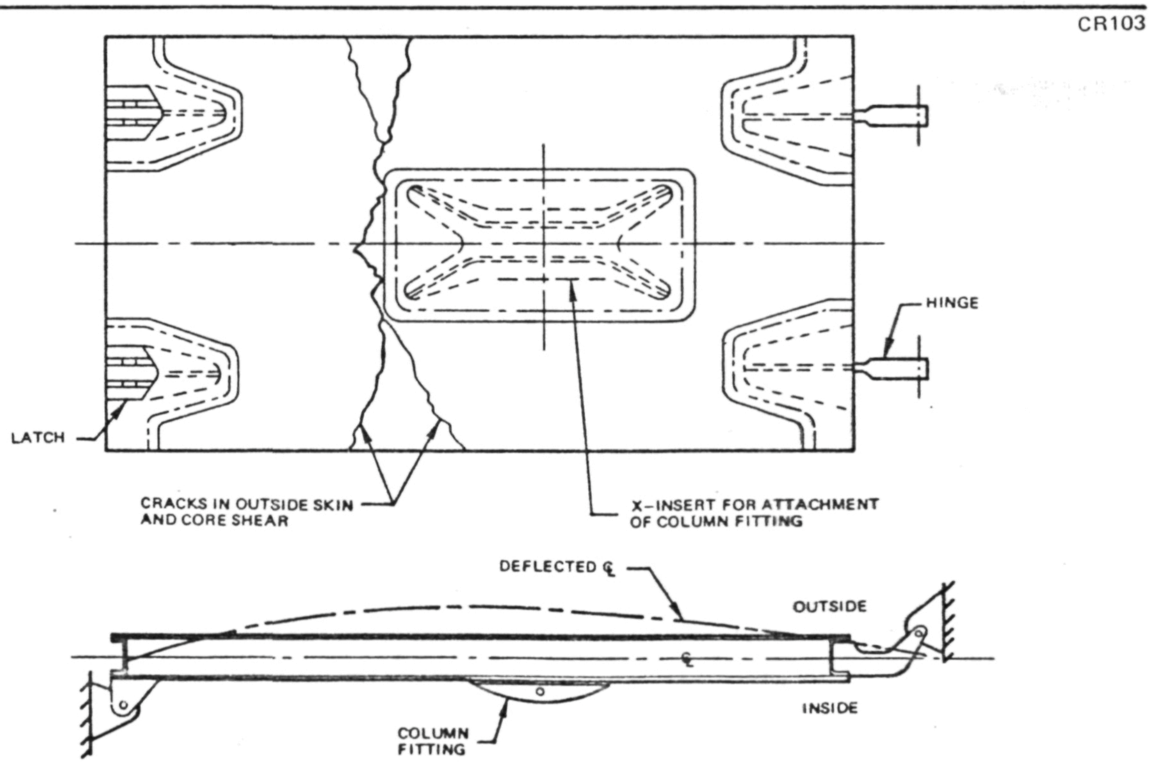

Figure 56. Door sector failure under concentrated load

the weak spot was the plain skin immediately outside the doubler in the region of the door where the bending curvature was large. The two extremities of the X-insert in this region created a condition of high stress concentration in the skin under which failure was initiated. In this respect, it is interesting to note that the crack pattern passes through the two outside corners of the doubler, as illustrated in figure 56.

Margins of Safety

The margin of safety based on the shear-out of the X-insert from the core under the ultimate load of 35, 100 N (7, 880 lb) was computed to be 0.73 in reference 1. With this margin (or a factor of safety of 1.73), the predicted failure load was 60, 400 N (13, 600 lb). In comparison to the actual failure load of 57, 500 N (12, 950 lb), the prediction is within about 5 percent.

At this point, a review of this apparent conservatism in the door design is in order. First of all, the concentrated load case (design condition B) is not the most critical design condition for the door. As found in reference 1, design condition A (uniform pressure load) was most critical. Under this loading, the full-size door was found to undergo essentially cylindrical bending with the door simply supported along its two long (4.51 m [177.5-in.]) edges. The critical section is at the midspan and in areas where the skin is not reinforced by doublers, such as section A-A in figure 57. The margin of safety, based on bending under ultimate pressure, was 0.17, which was not nearly as conservative as the 0.73 value found for design condition B.

This may be cause for the question, why then was not the test door sector built in the configuration representing section A-A? The reason was that, under the pressure load, the full-size door was simply supported at the edges with no load whatsoever acting on the local hinges and latches. To build and test a door to simulate this condition is identical to testing an oversized sandwich beam specimen. It was thought that more meaningful test results could be achieved with a test door sector as configured in this program.

The real conservatism in the door design comes from the use of a lower tensile allowable than was analytically predicted for the Narmco 5206-II Gr/Ep face sheets. The circumstances under which a tensile strength of 0.383×10^9 N/m^2 (55, 500 psi) was determined were fully documented in reference 1 and discussed briefly in this report under "Material Selection and Design Allowable." It suffices to say that, as a result, a conservative honeycomb core height of 0.073 m (2.88 in.) was selected.

Weight Estimate for Full-Size Door

Based on the results of the concentrated load test corresponding to design condition B, a factor of safety over the ultimate door load of 35, 100 N (7, 880 lb) was found to be 12, 950/7, 880, or 1.64. On this basis, the door thickness (or the honeycomb core height) could have been reduced to 0.073/1.64, or 0.0446 m (1.76 in.). However, the governing loading is still that of

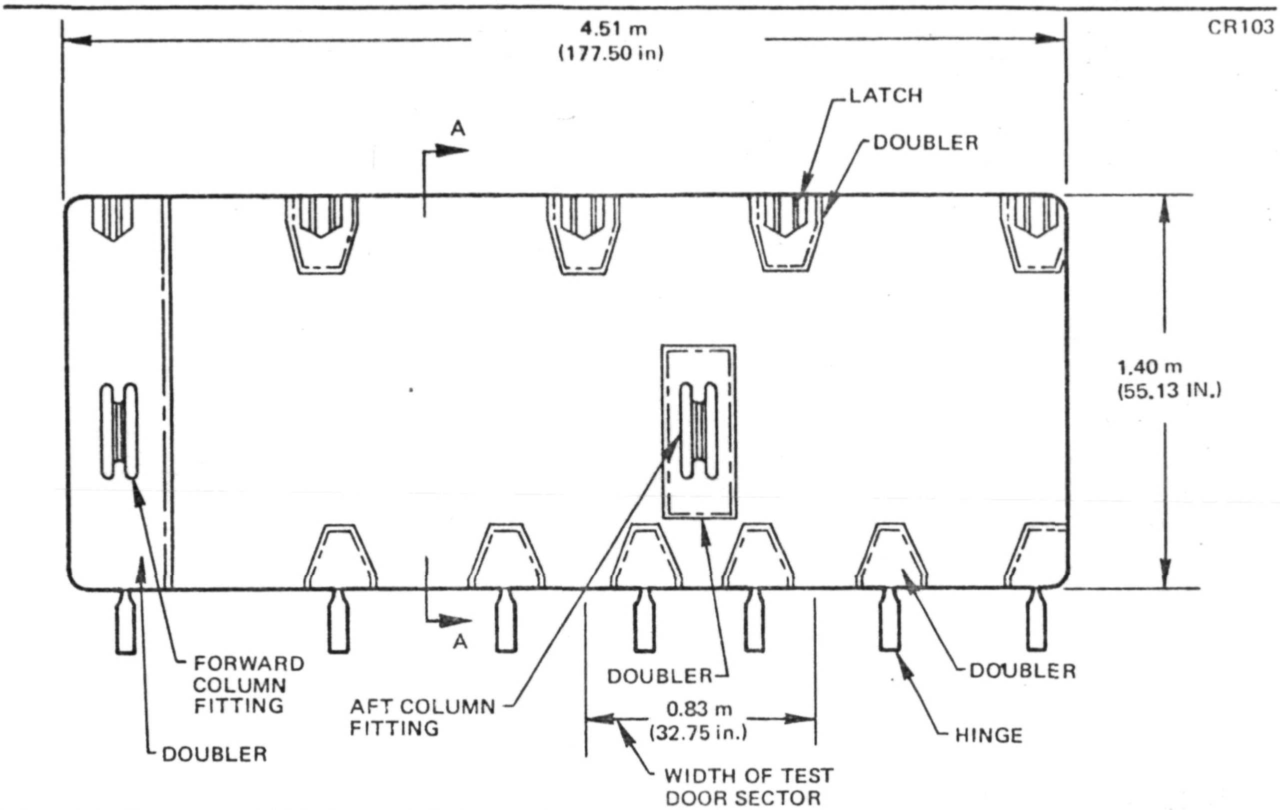

Figure 57. Schematic of full-size graphite/epoxy door

the uniform pressure in design condition A, as discussed above. As indicated in reference 1, based on a 0.383 GN/m^2 (55,500-psi) allowable tensile strength of the Gr/Ep skin and a core height of 0.073 m (2.88 in.), the margin of safety in bending-tensile stress was +0.17. The 0.383 GN/m^2 (55,500-psi) allowable had been derived from test results of IITRI-type coupons. Subsequent sandwich beam testing showed a range of 0.464 to 0.595 GN/m^2 (67,200 to 86,400 psi). The factor of safety (FS) reflecting the new minimum allowable of 0.464 GN/m^2 (67,200 psi) and zero margin of safety is therefore

$$FS = \frac{67,200}{55,500/1.17} = 1.42$$

On the basis of the foregoing, the core height becomes

$$t_c = \frac{2.88}{1.42} = 2.04 \text{ in.}$$
$$= 0.0518 \text{ m}$$

A new weight estimate was made for the full-size door with the reduced core height, as shown in table 8.

With the reduced door height, the central deflection of the door under the ultimate load of 35,100 N (7,880 lb) will be 0.036 m (1.42 in.) instead of the 0.018 m (0.71 in.) recorded in test no. 3.

An all-aluminum full-size door was estimated to weigh 71.03 kg

TABLE 8

NEW WEIGHT ESTIMATES OF THE FULL-SIZE GRAPHITE/EPOXY DOOR

Item	Old weight*		ΔW		New weight**	
	kg	(lb)	kg	(lb)	kg	(lb)
Face sheets	16.091	35.522	0	0	16.091	35.522
Doubler	4.130	9.117	0	0	4.130	9.117
Clips and channel	2.421	5.346	-0.290	-0.640	2.125	4.706
Fittings and inserts	6.920	15.277	-0.449	-0.991	6.460	14.286
Adhesives	9.450	20.847	-0.792	-1.750	8.650	19.097
Honeycomb core	22.903	50.559	-6.670	-14.750	16.220	35.809
Fasteners	0.453	1.000	0	0	0.453	1.000
Totals	62.368	137.688	-8.201	-18.131	54.129	119.537

*Weight reflects use of FM40 (instead of FM404) as the foaming adhesive.

**Weight reflects the door design of 0.0518 m (2.04 in.) honeycomb core height.

(156.80 lb), as reported in reference 1. The weight was based on the use of FM404 foaming adhesive. Since FM40 is the final choice as the adhesive material, the foregoing weight is increased to 71.1 kg (163.09 lb). The weight saving of the reduced height Gr/Ep door over the all-aluminum counterpart is computed to be 27.3 percent.

CONCLUSIONS

1. The structural adequacy of the door sector, the beam, and the column has been demonstrated by the structural tests designed to simulate the operating environments specified for the main landing gear door assembly of the Space Shuttle orbiter. The performance of the graphite/epoxy material in areas of highly localized stresses is particularly noteworthy.

2. Based on the test results and the more realistic design allowables eventually obtained for the graphite/epoxy material, the original graphite door design, as reported in the phase I summary report (reference 1), can be improved to show a 27.3-percent weight saving over the comparable aluminum counterpart. This it appears a full-size door of graphite/epoxy sandwich construction should be designed, fabricated, and tested for the latest configuration of the Space Shuttle orbiter. The weight saving over the metal design should be translated into a dollar value so that the cost-effectiveness of using graphite/epoxy in the Space Shuttle structure may be determined.

3. Based on the structural testing performed, the composite materials and the fabrication methods were shown to be suitable for the intended application. From a manufacturing standpoint, the methods developed to fabricate sandwich composite structures of this type have sufficient growth potential to scale up the full-size door in a production operation.

McDonnell Douglas Astronautics Company
Huntington Beach, California
November 1972

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NASA CR 112172 National Aeronautics and Space Administration EVALUATION OF METAL LANDING GEAR DOOR ASSEMBLY SELECTIVELY REINFORCED WITH FILAMENTARY COMPOSITE FOR SPACE SHUTTLE APPLICATION. Kong, S. J., and Freeman, V. L. November 1972. 81 pp. (NASA CONTRACTOR REPORT 112172) The summarized results of development of an advanced composite door assembly performed under NASA Contract NAS1-10785 are presented.	I. Kong, S. J., and Freeman, V. L. II. NASA CR NASA

Fabricated structural components included a 0.838-m (33-in.) by 1.4-m (55-in.) door sector, a column, and a pivot beam. The design and analysis were based on operating loads expected for the Phase B Shuttle Orbiter main landing gear door. The door sector was of full-depth honeycomb construction with graphite/epoxy skins, aluminum core, and metallic core inserts. The door sector successfully completed a structural testing program, including a uniform pressure test and a cyclic pressure test (both at room temperature), and a concentrated load test at 394°K (250°F). A weight saving of 27.3 percent was estimated for the graphite/epoxy door over a comparable all-aluminum honeycomb sandwich design.